SANITARY SCIENCE

THE SOIL

IN

RELATION TO HEALTH

GAFFKY'S BACILLI (enlarged 1,000 times).
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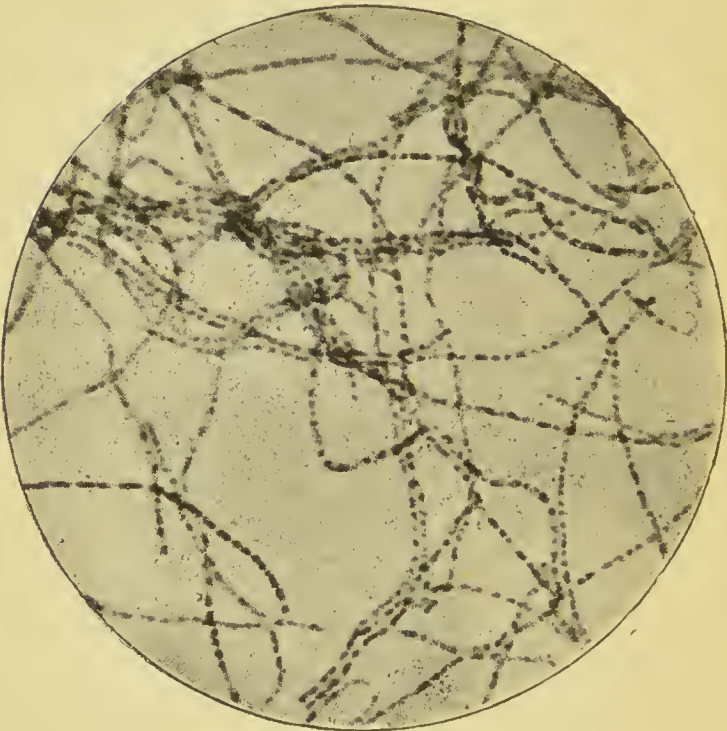
ANTHRAX BACILLI (enlarged 1,000 times).

THE SOIL

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RELATION TO HEALTH

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WITH ILLUSTRATIONS

" Principio hoc dico quod dixi saepe quoque ante
In terra cujusque modi rerum esse figuras ;
Multa cibo quae sunt, vitalia, multaque morbos
Incutere et mortem quae possint adcelerare."
—LUCRETIUS.

CONTENTS

CHAPTER IV.

THE CONSTITUENTS OF WATER DERIVED FROM THE SOIL.

CHAPTER V.

THE SOIL IN ITS RELATION TO AIR.

CHAPTER VI.

GEOLOGICAL DISTRIBUTION OF DISEASE.

INTRODUCTION

A WISH is frequently expressed by medical men,
more especially by those entering the public health
service, for some small book on the principles of
geology in so far as they concern sanitary science.
There is, so far as we are aware, no text-book on the
subject, and it is necessary to consult the large works
on geology and hygiene, and combine the information
obtained from the two sources—an extremely difficult
and unsatisfactory task.

It is with the object of supplying this deficiency
and also in order to emphasise the need of some
slight geological knowledge in matters of sanitary
science that the following pages are written ; and at
the present time, when it is to individual effort rather
than to legislative compulsion that we look for
sanitary progress, some points in the book may be
of interest to the householder as well as to the
medical man.

In order to keep the book within a small compass

much important matter has necessarily been left out. No mention has been made of such diseases as cholera and dysentery, which belong more especially to tropical countries—and stratigraphical geology is barely alluded to, since excellent text-books on that subject abound.

Few people are without ideas and opinions on the advantages and disadvantages of different kinds of soil, but how many of them base their opinions on any real knowledge of the properties of the ground? Owing to the absence of a little special knowledge which does not happen to enter into the conversation or literature of every-day life, many of the ideas prevalent upon these subjects may well be classed with those popular delusions which still cling even to educated minds.

Of course there may be, and generally is, a certain element of truth in popular ideas, however erroneous.

To take an outside case for example :—The knowledge that sulphur is insoluble in water would show the absurdity of placing a piece of sulphur in a dog's drinking water, yet this ceremony is performed in every well-regulated dog-kennel—possibly because it was long ago known that sulphur administered by the mouth or used as an inunction has some curative effect in certain cutaneous diseases of the dog.

Or again, to take an instance allied to the present subject, the knowledge that tetanus (lock-jaw) results from the introduction into a wound of a specific

organism, the *tetanus bacillus*, would condemn the popular notion that tetanus is invariably produced by a sufficiently deep cut between the thumb and first finger. It is certainly true that tetanus sometimes results from such an injury (provided that the specific poison is also present), simply because dirt, which is the habitat of the tetanus bacillus, is apt to be introduced into such wounds, which are often jagged and consequently difficult to cleanse.

Again, the serious consequences which occasionally result from the scratch of a cat are popularly supposed to be due to some venom secreted by the cat's claw, whereas in reality the claw is but the inoculating needle ; the ground over which the cat has walked, containing organisms such as those of malignant œdema or tetanus, is the *fons et origo mali*.

It is perhaps too much to expect that the following pages will serve to overthrow any dangerous popular notion, such a one for instance as the following which it was our lot, only a short time ago, to overhear. A child with a small pocket tumbler in her hand asked permission of her nurse to drink some of the water from a "spring" situated beside a road at the end of a group of cottage gardens ; permission was readily given with the remark that "country" water is always pure and good—a doctrine which we have reason to believe is commonly held, and one which we trust will be sufficiently disproved in the ensuing chapters.

Popular ideas about the hygienic importance of the ground mostly date from a time when there was little or no scientific knowledge of the subject. There were no statistics to be used (or abused); epidemic outbreaks of disease were regarded as "visitations"; the existence of ground water was hardly realised; the importance of ground air was not suspected; the geological features of a district were not taken into account; and the action of micro-organisms had not been discovered.

For instance, we find that by most people soils are condemned or recommended without a question being asked about the subsoil; yet the character of a soil such as gravel will depend largely upon the nature of the rock which lies beneath it. Again, it is frequently stated that sand is a healthy and clay an unhealthy soil. But we shall presently see that typhoid fever cases are most numerous in that part of Dublin which is built upon gravel, and that the highest mortality from epidemic infantile diarrhœa occurs at Leicester, where the soil is sandstone. The words healthy and unhealthy as applied to the soil must be merely relative terms.

In this matter there are two common errors.

On the one hand the soil is frequently held responsible for illnesses ·with which in reality it has nothing whatever to do. A case recently came under our notice. A family who for many years had lived in a town situated upon a deep bed of gravel moved

into a house built on the clay. On taking up their new residence nearly all the family suffered from sore throats of a septic nature, which were at once attributed to the " horrid damp clay." It was found, however, on investigation, that the ventilating shaft to the soil-pipe opened just underneath one of the best bedroom windows, and the waste-pipe to the bath was untrapped and joined the soil-pipe ; when these and other defects were remedied there was no further trouble from sore throats.

On the other hand it will be clear from the following pages that many diseases which are commonly ascribed to other causes may be directly or indirectly due to the nature of the soil.

The properties of a given soil are, *cæteris paribus*, everywhere the same, and an acquaintance with these properties must be the foundation of our knowledge ; but such knowledge is quite useless unless we can also make use of it under the actual conditions of modern life.

With the primitive conditions of life which prevailed in the early periods of the world's history a simple knowledge of the nature of the ground would have been sufficient.

But at the present time most problems relating to the soil in its connection with public health are necessarily very complex.

The aggregation of people in large districts and towns renders it necessary that arrangements on a

large scale should be made for the collection, removal and disposal of refuse of all kinds, for obtaining water, and for supplying many other requirements of civilisation which directly or indirectly concern sanitation. The methods by means of which these arrangements are carried out may in themselves be a source of danger to the community.

For instance, sewage under the water-carriage system is removed from houses by means of drains and sewers ; these may be, and as a matter of fact often are, defective and allow some of the liquid portion of the sewage to soak into the ground, the more porous the soil the greater the extent of the pollution. A common method of treating the sewage after removal from houses is by means of land filtration. Not many miles from London the sewage of a large district is applied to a small area of land quite insufficient in size, and the soil, being clay, has become water-logged.

Again, water may be taken from a river fed above the intake by streams which collect upon cultivated and manured land into which sewage is sent. In its distribution to houses by means of pipes water may be contaminated, more especially if the supply is intermittent. Cases are recorded in which gases from defective gas-pipes and sewers have found their way into water-mains. In all such questions the nature of the soil will greatly influence the relative risks.

It is obvious then that we have to consider not

only the properties of different soils but also how far the dangers which may arise from any of the sources we have indicated are augmented or diminished by their nature.

To take a simple example :—Suppose that a village is situated on a shallow bed of water-bearing gravel overlying impermeable clay. The water supply is obtained from shallow wells and the sewage is deposited in cess-pits. These conditions favour contamination of the drinking water. If, on the contrary, the soil were clay only there would be, as will be shown in a subsequent chapter, less chance of the water becoming polluted, but on the other hand water from the clay being stagnant surface water is not itself good for drinking purposes. And in the absence of surface drainage the clay would be wet and probably cause structural dampness of the houses and prevalence of diseases which are directly or indirectly associated with dampness.

Moreover, we are handicapped at the outset. Years of neglect of the first principles of sanitation leading to fouling of the soil add considerably to our complications. Reports of medical officers of health from different parts of the United Kingdom verify this statement. For instance, Sir Charles Cameron, D.P.H., Medical Officer of Health for Dublin, recently stated that the practice of storing excreta in pits has existed in Dublin for centuries, and has caused

the soil to become impregnated with filth and organisms.

All such considerations as those mentioned above are more properly matters concerning sanitary science and do not enter into the scope of the following pages, which treat only of the nature of the *soil* as it may affect health. For this reason it is all the more important to bear them constantly in mind, and to remember that a knowledge of the properties of rocks and soils, though necessary, is by no means sufficient.

The subject to be treated is a very wide one and readily admits of romance. We shall endeavour to confine ourselves, as far as possible, to facts, merely emphasising the importance and complexity of the subject, and we now pass on to a more systematic consideration of the different soils and the manner in which they may influence the well-being of the community.

THE

SOIL IN RELATION TO HEALTH

CHAPTER I

ROCKS AND SOILS

" The nature of the various soils now see."
—DRYDEN *after* VIRGIL.

THE ORIGIN OF ROCKS

THE ground on which we live consists of a surface
layer or "soil" such as gravel, sand or clay, but the
underlying material or subsoil is often of a different
nature; and in sinking a well or in making a deep
boring a succession of different materials is usually
encountered.

The uppermost layer is due to the weathering
action of the frost, rain and air upon the exposed
ground, so that in general the surface soil is simply
the result of the disintegration and decay of the
subsoil which immediately underlies it. In any place
where animal and vegetable life are supported, the

B

surface soil is covered with a dark-coloured earth consisting mainly of the products of decomposition of organic matter, such as the decay of plants, and is known as mould or "humus."

As we pass downwards below the surface different sorts of "rock" succeed one another, usually in more or less parallel layers of different thicknesses.

A succession of this sort is shown in the well section on p. 25.

The word rock is applied to any of the materials of which the earth's surface is composed, such for instance as granite, sandstone, limestone, clay, whether they are hard like granite, or soft like sand and mud.

Now two sorts of rock are found upon the earth: (1) those which from their crystalline or slaggy structure or from other features are known to have solidified from a molten condition, and have therefore been produced by the action of heat; these are known as the **Igneous Rocks;** such are granite, basalt and volcanic lava; (2) those which consist of particles deposited in parallel layers and have been laid down by the action of water; these are known as the **Aqueous** or **Sedimentary Rocks;** such are sand, limestone and mud.

There can be little doubt that the earth was originally in a molten condition, and that as it cooled a solid crust was formed round the liquid core.

During the subsequent history of the earth this crust has been the seat of various geological changes. For instance, eruptions of the underlying molten

material have doubtless taken place from time to time through or into the crust.

When some of this molten rock bursts through the crust of the earth in a modern volcanic eruption it issues as liquid lava ; when the lava cools it solidifies, and in solidifying crystallises.

Now among the rocks of the crust are to be found many which possess a structure identical with that of a modern lava. The trap-rock of the Giant's Causeway in county Antrim is a familiar instance. Sometimes these rocks bear obvious signs of their volcanic origin ; thus in Auvergne the valleys are filled with long streams of basaltic rock, and these can be traced to extinct volcanoes whose craters are still quite conspicuous, although the eruptions took place at a time of which there is no historical record.

Igneous rocks must have constituted the whole original crust of the earth ; they now form a large part but not the greater part of the earth's surface ; no doubt they exist in much larger masses below the surface.

After the crust of the earth had solidified it was subjected through long ages to the wearing action of frost, water and wind ; valleys have been constantly channelled by the continued flow of rain-water and rivers ; cliffs have been eaten away by the washing of the sea waves ; the hardest rocks have crumbled beneath the rending power of moisture and frost ; and sands and dust have been blown by the wind from every exposed surface where rocks have been broken up by these agencies.

The particles carried down by rivers or washed into the sea have been slowly deposited in the still water, and vast accumulations of fine sand and mud have been gradually laid down in river-plains, in lakes and on the ocean bed ; these deposits consist for the most part of parallel layers or "strata."

Fig. 1 represents a succession of strata which have become tilted by earth-movements after having been deposited in horizontal layers.

FIG. 1

Hence it is clear that the sedimentary rocks must consist of the *débris* and ruins of the igneous rocks gathered together by the action of wind and water, and that they will usually be "stratified," the lowest layers being the oldest.

We must first consider the original or igneous rocks.

THE IGNEOUS ROCKS

These are distinguished by their similarity to the lava of modern volcanic eruptions and are generally crystalline.

They all consist mainly of oxygen and silicon with more or less aluminium, iron, calcium, magnesium,

potassium, sodium and hydrogen. These elements are combined to form silica (SiO_2) and certain complicated silicates. Silica is the mineral quartz; the silicates are the other minerals which build up the igneous rocks, and are called "rock-forming minerals."

In a crystalline rock each crystal consists of one of these minerals.

Now each of the rock-forming minerals may be regarded as formed by the union of silica (SiO_2) with one or more of the "basic" oxides, alumina (Al_2O_3), ferrous oxide (FeO), ferric oxide (Fe_2O_3), lime (CaO), magnesia (MgO), potash (K_2O), soda (Na_2O) and water (H_2O). Some of the silicates contain more silica than others; roughly speaking those silicates which contain iron and magnesium are the least siliceous (or the most basic).

According to the total amount of silica which they contain the igneous rocks are distinguished as *acid* and *basic*.

The acid rocks contain about seventy per cent. of silica, and are light-coloured and less dense; of these granite is a representative.

The basic rocks contain about fifty per cent. of silica, and are heavier and darker; of these basalt is a representative. Igneous rocks containing about sixty per cent. of silica are generally referred to an intermediate class.

We must now consider the principal minerals of which these rocks are composed.

THE MINERALS OF THE IGNEOUS ROCKS

(1) **Quartz** (SiO_2) is pure silica; it is a hard, colourless, glassy substance, and is the most characteristic mineral of the acid rocks; whereas it does not occur at all as a constituent of the basic rocks. It may easily be distinguished by the eye or with a lens, generally as glassy blebs or granules filling the interstices between the other minerals.

The most important character of quartz from our present point of view is its durability, which is due to the hardness and the almost complete insolubility of the mineral, so that it survives unchanged when other substances are decomposed or destroyed.

(2) **Felspar** is a silicate of aluminium and of potassium, calcium or sodium, and is the most universal of all the rock-forming minerals.

There are two varieties of felspar, namely potash-felspar ($K_2O.Al_2O_3.6SiO_2$) and soda-lime-felspar; the former contains the greatest proportion of silica and is characteristic of the acid rocks; the latter is frequent in the basic rocks.

Pure felspar is a clear glassy mineral, nearly as hard as quartz (not scratched by a knife); it is often coloured pink or brown.

Under the influence of exposure to air and rain, and the other changes to which rocks are subject, felspar, unlike quartz, is prone to alteration and is therefore generally opaque, granular and somewhat decomposed. Potash-felspar finally loses its alkali

and becomes decomposed into clay which is an aluminous silicate.

(3) **Mica** is a silicate of aluminium, potassium, magnesium and iron, with a little fluorine and water ; it always occurs as flat scales or plates which easily flake into thin elastic leaves ; this characteristic property is familiar in the large sheets which are used as covers for lamp glasses and are erroneously called "talc."

The colour varies considerably with the amount of iron &c. contained in the mineral.

Mica is not very liable to chemical alteration, but it readily breaks up by continued attrition into a scaly sand or dust.

The other minerals of the igneous rocks are mostly silicates of calcium, magnesium, iron and aluminium ; the silicates of calcium and magnesium being especially abundant in the basic rocks.

VARIETIES OF IGNEOUS ROCK

Igneous rocks do not cover any very large area in the British Isles, and it will be enough for our purpose to mention the two most important varieties, one belonging to the acid and the other to the basic group.

Granite is an acid rock, a granular mixture of quartz, potash-felspar and mica ; the felspar is often conspicuous in the granite used for building stone as large pink tablets, the mica as black or silvery scales ; granite occurs in large masses in Devonshire and Cornwall, in Leicestershire, in the

Lake District, in Aberdeen, Kirkcudbrightshire and many other parts of Scotland, and in Ireland.

Basalt (included under the old names of Green-stone and Trap-rock) is a heavy dark-coloured finely crystalline basic rock, consisting of minute crystals of felspar with silicates of iron, magnesium and calcium. Basalt generally occurs in sheets and walls penetrating other rocks and is found in this form in many parts of Scotland ; of this nature is the so-called "toad-stone" of Derbyshire ; in county Antrim it covers a large area of country.

When an igneous rock consists of angular frag-ments derived from volcanic eruptions it is called a **volcanic breccia;** "tuff" and "ash" consist re-spectively of fine particles and dust which have originated in this way.   Some of the igneous rocks of the Snowdon district and of the Lakes are of this nature.

When the constituents of a crystalline rock are arranged in parallel layers it is said to be "schistose."

Mica-schist, for instance, is a rock which consists of parallel flakes of mica together with other crystallised minerals.

Gneiss is a schistose rock of the same mineral composition as granite, in which the quartz, felspar and mica are ranged in parallel layers.

The greater part of Northern Scotland consists of crystalline schists.

A schistose structure is generally supposed to be the result of alteration, and has certainly in many cases been impressed upon rocks by pressure, just

as putty may be squeezed or rolled into a streaky mass.

This leads us to consider the changes to which the igneous rocks have been subject during geological ages.

ALTERATIONS OF THE IGNEOUS ROCKS

These changes are of two kinds, mechanical and chemical.

(1) **Mechanical change.**—Through the pressure and friction caused by shrinkage of the crust, by volcanic movements and disturbances, combined with the action of heat, and by the weight of overlying masses, a rock may be squeezed into a schist or may have its texture and constitution entirely altered ; this is, for example, the process by which the volcanic ashes of North Wales and the Lake District have been converted into hard flinty rocks ; and many of the schists are supposed to have been originally sedimentary rocks.

Instances of such change are to be found near granite masses, such as those which protrude through the slates of Devon and Cornwall, and in the neighbourhood of volcanic centres ; these are often surrounded by schistose rocks, constituting a so-called "zone of contact" between the igneous and sedimentary rocks.   (Fig. 2, p. 10.)

Further—by the action of frost, rain and wind, rocks of all sorts are broken up into fragments, and these by continued friction, especially through the rolling action of running water and the wash of sea-

waves, are worn down into fine particles ; some of these may be destroyed or dissolved during the vicissitudes which they experience ; those which survive contribute the greater part of their material to the gravels, sands and other sedimentary rocks.

(2) **Chemical Change.**—By the oxidising action of the air, by solution in water, especially in rain-water which contains carbonic acid, and by the corrosive action of other liquids and gases which percolate through the rocks and permeate them, almost
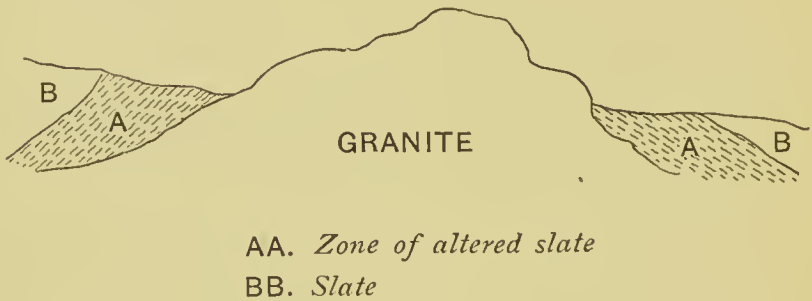
AA. *Zone of altered slate*
BB. *Slate*
FIG. 2.

all minerals are subject to change and are converted into other minerals ; the soluble portion of a mineral may be extracted and carried away in solution to be redeposited elsewhere, while the residue remains behind. Thus water containing carbonic acid will extract the calcium from various silicates of lime in the form of carbonate of lime, and the latter may be deposited from the solution as the mineral calcite or limestone ; the aluminium contained in such silicates may remain in the form of aluminium silicate which constitutes the basis of clay.

Metamorphism.—A rock-mass which has been altered *in situ*, as distinguished from those which have been broken up, transported and redeposited elsewhere as sedimentary rocks, is said to be "metamorphic." The crystalline schists are probably metamorphic, and have resulted from the alteration of sedimentary strata or other rocks. Serpentine (silicate of magnesium), which constitutes nearly the whole of the Lizard peninsula in Cornwall, is a metamorphic mineral due to the chemical alteration of some sort of basic rock ; limestone may be metamorphosed into crystalline marble, slate into schist.

Metamorphic action may be both mechanical and chemical.

We have now to consider briefly the chief minerals generated by the various processes of alteration to which the igneous rocks have been subjected ; that is to say, the minerals which go to make up the sedimentary rocks.

THE MINERALS OF THE SEDIMENTARY ROCKS

(1) **Quartz** (SiO_2) is such a durable mineral that it generally occurs as unaltered glassy grains which have merely been broken and worn down by friction, and must have originally existed as quartz in the rocks from which it was derived.

Sand and sandstone consist almost entirely of quartz grains. Silica is soluble in alkalies and in alkaline carbonates (also to an extremely limited

extent in water) and it is found in many spring-
waters ; much of the quartz found in nature must
have been deposited from siliceous solutions ; the
process is in fact now going on in the hot springs of
Iceland and New Zealand. " Chalcedony," a variety
of silica which is familiar as the non-crystalline
portion of agate, has originated in this way.

It is not then surprising that silica is the cementing
material of many sedimentary rocks, having been
deposited by the percolation of siliceous solutions.

Silica is secreted from water by diatomaceæ,
sponges, rhizopods and other organisms, and vast
masses of " diatomaceous earth " are found which
consist solely of the siliceous scales and skeletons of
these organisms.

Flint is silica which is found in lumps in the chalk
and is doubtless of organic origin, since it invariably
contains sponge-spicules.

(2) **Calcite,** calcium carbonate (Ca CO_3), is one of
the commonest of all minerals, and is the material of
which limestone consists ; it is a white or colourless
mineral, easily scratched by the knife, and may be
recognised by its violent effervescence when touched
with a drop of acid ; when crystallised, it readily
breaks up into glistening fragments. Calcite has
always been deposited from solution and is readily
soluble in water which contains carbonic acid ; it thus
acts as the cementing material of the many sedi-
mentary rocks which have been impregnated with
calcareous solutions. The " petrifying springs," such
as those of Matlock and Knaresborough, are familiar

examples of calcareous solutions. Carbonate of lime is also secreted from water by many organisms (corals, molluscs, echinoderms, &c.) and chalk consists entirely of the calcareous skeletons of foraminifera. **Dolomite** (or magnesian limestone) is a variety of carbonate of lime which contains a large proportion of magnesium carbonate.

(3) **Clay** (aluminium silicate). The purest variety is the so-called "China-Clay" ($Al_2O_3.2H_2O.2SiO_2$) or Kaolin, which is found as a soft snow-white powder resulting from the decomposition of the felspar in granite, and consists of extremely minute scales. It is found in vast masses in Cornwall (especially in the St. Austell district) and can be easily dug out with the spade.

The other varieties of clay are all impure silicates of aluminium of various colours ; they resemble china clay in being soft powdery materials which yield a characteristic earthy smell when breathed upon, and when mixed with water they cake into mud.

Clays are the commonest decomposition products of the silicates, but are not themselves liable to further alteration.

(4) **Oxides of Iron** (Hæmatite and Limonite). These are red and yellow, earthy or powdery minerals of very widespread occurrence.

Hæmatite (Fe_2O_3), or Red Ochre, is the red anhydrous oxide ; **Limonite** or Yellow Ochre is a hydrated oxide of iron. They are the substances which impart colour to most of the brown, red and yellow rocks ; and are the commonest decomposition products of

minerals containing iron, being usually found wher-
ever oxidation has taken place.   For this reason most
rocks which have been weathered by exposure to the
air acquire a brown, red or yellow tint.   The colour
of chalybeate waters is likewise due to the yellow
ochre precipitated as a slime by the oxidation of iron
salts which they contain.   Most rocks which contain
iron become red when they are heated, owing to the
production of the red oxide.

TYPICAL SEDIMENTARY (AND METAMORPHIC) ROCKS.

The Sedimentary Rocks are of three kinds :
Siliceous, or those which consist mainly of silica ;
Calcareous, which consist mainly of carbonate of
lime ; and Argillaceous, which consist mainly of clay.

A. **The Siliceous Rocks** (hard, gritty and porous).

The following are some of the more important
varieties :

Sand consists almost entirely of rounded grains
of quartz, which have doubtless been derived from
the wear and tear of igneous rocks, such as granite
and other acid rocks.

The finer and older varieties are nearly pure quartz-
sands, but those of more modern origin contain
numerous particles of other minerals such as felspar
and mica.

Sands may be either fluviatile (river-sands), or of
marine origin, or blown-sands (collected by the wind).
Pure sands are practically unalterable except by heat,
and yield nothing to the water which percolates

through them, but on the other hand exert a valuable filtering action upon water containing mechanical impurities.

Sandstone is sand which has been compacted by pressure and cemented by some mineral material so as to form a coherent rock. The cementing material is generally calcareous (calcite) or ferruginous (limonite); it may also be siliceous or felspathic; the more coloured sandstones, such as the red sandstone of Devonshire, are ferruginous.

Sandstones are porous and allow water to percolate, and like sand exert a filtering action.

Grit is a name applied to sandstone in which the grains are rather larger than usual.

The Cumberland Millstone grit consists of grains of quartz bound by a siliceous cement.

Flagstone is a fissile variety which splits into slabs.

Greensand is a sandstone which derives its dirty green hue from particles of glauconite, an earthy green silicate of iron which is a decomposition product of certain calcium and magnesium silicates of the igneous rocks, and is disseminated through the greensand; the glauconite is supposed to have been deposited by organic agency since it is associated with the remains of foraminifera.

Gravel consists of loose water-worn pebbles which have not been reduced to the dimensions of sand grains; it is the almost universal lining of river beds, and (as shingle) of sea-coasts; the pebbles may consist of all manner of hard rocks, granite, felsite, sandstone &c., as well as the simple minerals quartz and flint.

Conglomerate is a gravel compacted together by some cementing material, which may be either calcareous, argillaceous or siliceous.

B. **The Calcareous Rocks** (effervesce with acids and yield to the knife).

Limestone consists entirely of calcite, whether crystalline, compact or earthy. The limestones have either been deposited from solution or consist of the remains of calcareous organisms ; the deposition of carbonate of lime from aqueous solutions at the present time is familiar in the so-called petrifying springs, and in the growth of stalactites. There are numerous varieties of limestone distinguished by their structure, mode of origin and the organic remains which they contain.

Oolitic Limestone, or Oolite, consists entirely of little spherical grains like the roe of a fish. **Magnesian Limestone**, or Dolomite, is a hard crystalline limestone containing carbonate of magnesium.

Among the limestones of organic origin are to be mentioned : *crinoidal and coralline limestones*, which consist almost entirely of the remains of crinoids, corals and molluscs ; *shell-sands and shell-marls*, which are composed mainly of shells cemented together by a calcareous cement : but the most important variety, on account of its immensely wide distribution, is **chalk ;** this white powdery rock is composed almost entirely of the remains of Foraminifera, and is of marine origin. To metamorphic action is to be ascribed the formation of

crystalline marble, which has a granular crystalline structure like that of sugar ; it may have resulted from any of the above-mentioned varieties by the heat and pressure of eruptive igneous rocks.

C. **Argillaceous Rocks** (emit an earthy odour when breathed upon, adhere to the tongue and are more or less plastic).

Clay. The purest clay, as mentioned above, is the white china-clay which results from the decomposition of the felspar of granite ; the ordinary clays are mixtures of various silicates of alumina with ferruginous and other impurities ; they are very compact, owing to the extreme minuteness of their particles, and soften in water into a mud.

Fire-clay is a pure siliceous clay found associated with seams of coal which does not fuse, even under intense heat.

Fuller's earth is a clay which contains a large proportion of water, does not adhere to the tongue and is not plastic.

It sometimes results from the decomposition of basic rocks ; fuller's earth is found in large quantities in the greensand at Nutfield in Surrey.

One of the most important properties of clay is its impermeability, so that a bed of clay holds water and prevents it from sinking into the underlying strata.

Clays are always impure and by the varying proportion of siliceous or calcareous material which they contain pass gradually into sands and lime-stones.

Intermediate varieties are the following : **loam** is a mixture of clay and sand and is consequently a lighter soil than clay and less impervious to water ; **brick-earth** is a ferruginous loam used for the manufacture of bricks ; **marl** is a mixture of clay and carbonate of lime, sometimes containing a considerable proportion of the latter, but generally more or less plastic ; it is common near chalk and other calcareous formations.

Clay ironstone is a mixture of clay and carbonate of iron ($Fe\ CO_3$), but contains such a large proportion of the latter that it has more the character of a brown limestone than of a clay ; it usually occurs in nodules and beds associated with the coal-bearing formations.

Altered Clays.   The clays have been mostly laid down as stratified deposits in water ; when compacted together by the weight of overlying deposits they are compressed into a harder rock which tends to split along the planes of stratification.   This process leads to the formation of **shale,** which is merely a hardened laminated clay showing a tendency to split into sheets.   The shales, like the clays from which they are derived, are mostly impure.

Slate is a clay which has been compressed into a hard compact rock ; it possesses in a very marked degree a fissile character enabling it to be split into perfect plates across the direction in which it has been compressed.

Conspicuous in this respect are the roofing slates of North Wales and Cornwall.

Boulder Clay (or Till) is the detritus and mixed deposit left by glaciers and ice sheets which have crept across the surface of the earth in previous ages ; it is an impure sandy clay containing pebbles and striated boulders of all sizes and the most widely different materials.

Loess is a fine calcareous loam mixed with various minute organic remains, and is probably the result of the drifting and deposition of fine dust by the action of the wind. Some of the brick-earth is a deposit of this nature.

MINERAL DEPOSITS

Finally, there are two minerals which occur in sufficiently large deposits in England to be of great importance : these are :

Salt, sodium chloride (NaCl), which occurs in large white masses, and is of course easily recognised by its taste. It is so soluble in water that most of the underground salt deposits of Cheshire are worked by pumping up water containing the salt in solution ; the water is then evaporated and the salt allowed to crystallise.

No less than two million tons of salt are produced annually from the salt deposits in England.

Gypsum (or Selenite), hydrated calcium sulphate ($CaSO_4 . 2H_2O$), also occurs in large white masses (alabaster) ; the mineral is recognised by its softness, and by the fact that when heated it is converted into plaster of Paris. It is largely burnt for this purpose. When crystallised it is transparent and readily splits

up into thin glistening flakes or plates; in England it is associated with the salt deposits.

THE DECOMPOSITION OF ROCKS

From the foregoing survey it is clear that the earth's crust consists mainly of the elements oxygen, silicon, aluminium, calcium, magnesium, potassium, sodium and iron. It has been estimated that about 47 per cent. is oxygen, about 27 per cent. silicon, and about 8 per cent. aluminium; the igneous rocks are almost entirely silicates; the softer sedimentary rocks consist mainly of silicates, carbonates and oxides.

By their decomposition the acid rocks yield clay, silica and alkaline carbonates, while the basic rocks are resolved into clay and the carbonates of calcium, magnesium and iron.

Generally speaking the acid rocks weather into clayey soils which contain particles of quartz, felspar and mica; granite for instance into a loam; the schists also decompose to a loamy soil: the basic rocks yield a marl or coloured clay.

The decomposition of rocks into surface-soils is not by any means a purely chemical process due merely to the direct action of air and rain, but is largely aided—if it is not mainly carried on—by the presence of certain low forms of vegetable life. In the first place, as has been described by Johnstone, *rock-lichens* (algæ and fungi) begin to grow where their spores have been deposited upon the decomposing surface of the rock; they absorb moisture and make use of the

carbonic acid of the atmosphere; in this way carbonaceous material is constantly introduced into the weathering surface of the rock ; one lichen succeeds another, each growing upon the remains of its predecessors, with the help of various " **bacteria** " which promote the decomposition of the dead material. The lichens are in their turn succeeded by *mosses*, and a constantly increasing thickness of vegetable matter covers the rock which is gradually disintegrated by the growth of the plant life ; organic acids are produced, the constituents of the rock are dissolved out by these and by carbonic acid ; and finally the processes of both mechanical and chemical disintegration are continued by the higher plants which succeed the lichens and mosses, thrive on the vegetable mould which they have produced, and send down their roots to penetrate the joints and crevices of the rock. The nature of vegetable mould, and the important part played by living bacteria in the soil will be more fully considered in Chapter II.

THE DISTRIBUTION OF SOILS

The various soils described above are found in many different parts of the British Isles ; a general idea of their distribution and of their relation to the underlying strata can only be gained by some geological knowledge of the country.

The structure of Great Britain may be roughly understood by reference to any good geological map in which the order of succession of the various sedimentary rocks is indicated : generally speaking,

the successive sedimentary strata in England are arranged like a series of overlapping leaves, dipping under each other towards the south-east while their exposed edges run from north-east to south-west. The lowest and therefore the oldest strata are on the western side, the highest and most recent strata are on the eastern side of the island. The same structure is continued in the southern portion of Scotland, but the northern and north-western Scotch area is mainly occupied by crystalline schists ; these underlie the sedimentary and fossiliferous rocks and precede them in point of age.

Each geological epoch may include a great variety of rocks, as is clear from the following table, which gives the most important formations of England and Scotland, beginning with the oldest.

The names of the divisions merely indicate the relative geological age and not by any means the nature of the formations.

Thus, for example, the Oolitic are older than the Cretaceous formations, and underlie them ; again a well sunk through the Eocene deposits (London clay) of the London district may be expected to reach the chalk of the Cretaceous system if carried to a sufficient depth.

TABLE OF STRATIFIED ROCKS

Archæan.   Crystalline schists of N.W. Scotland.
Cambrian.   Slates and flagstones of N. and W. Wales, &c.

Silurian. Shales, slates, sandstones, grits and limestones of Central Wales, Shropshire, Cumberland and S. Scotland.

Devonian. Slate and limestones of Cornwall and Devon; "Old red sandstone" of S.E. Wales, Shropshire and N.E. Scotland.

Carboniferous. "Mountain limestone" of Bristol, Monmouthshire, Derbyshire, Westmoreland, Cumberland and Northumberland;

Limestones and sandstones of Central Scotland;

Sandstones and grits, and "Millstone Grit" of S. Wales, Derbyshire and Yorkshire; grits and shales "culm measures" of N. Devon;

"Coal measures" (coal with shales, clays and sandstones) of S. Wales, Stafford, Warwick, Derbyshire, Lancashire and Durham. The "Potteries" are situated on the clays of the upper coal measures.

Permian. Dolomite "magnesian limestone" of Durham and Yorkshire.

Trias. "New red sandstone" of Lancashire, Cheshire, Leicestershire and Yorkshire.

"Red marl" of Cheshire and Central England, extending to Devonshire.

In the red marl are contained the Worcestershire and Cheshire deposits of salt and gypsum.

Lias. Clay, limestone and marl, extending from Dorsetshire to Yorkshire east of the Trias.

Oolite. Limestone, "Bath oolite," "coral rag," "Purbeck and Portland stone."

Clays: "Oxford clay," "Kimmeridge clay": the

whole series extending from Dorsetshire to Yorkshire, east of the Lias.

Cretaceous. "Weald clay" and "Hastings sand" of Sussex; greensand, gault clay, chalk marl and chalk, extending from Norfolk to Dorset east of the Oolite, and branching from Hants to Sussex (South Downs) and to Kent (North Downs), occurring also in East Yorkshire; the Weald clay is exposed in a large area of Sussex and Kent between the North and South Downs where there is no overlying chalk.

Eocene. "London clay" and "Bagshot sands" of Hampshire and of Berkshire, Middlesex and Essex; fluviomarine series of the I. of Wight.

Pliocene. "Coralline and red crag" the marly limestone of Suffolk; sand and loam of East Norfolk.

Boulder Clay covers a large part of Lincolnshire, Norfolk, Suffolk and Essex, and a somewhat similar clay, known as the Till, occurs in Scotland.

Recent. The alluvial deposits of rivers; sands and gravels.

Although the "out-crops" or upturned edges of the sedimentary strata exhibit the above sequence, it by no means follows that representatives of all these epochs are encountered in a deep boring; they may thin out and disappear in different regions, so that at any one spot some members of the series may be entirely missing.

The deep boring at Meux's Brewery in Tottenham Court Road which has been carried to a depth of 1,146 feet passes through the following strata (Fig. 3);

London Clay . . . . 64 feet. ⎫
Woolwich and Reading Beds 51 ,, ⎬ Eocene.
Thanet Beds . . . . 21 ,, ⎭
Chalk . . . . 656 ,, ⎫
Greensand . . . . 28 ,, ⎬ Cretaceous.
Gault . . . . 160 ,, ⎭
Oolite (limestone and marl) . 64 ,,

Well at Meux's Brewery
Tottenham Court Road.

FIG. 3.

and enters the old red sandstone at a depth of
1066 feet. In this series the whole of the Lias,
Trias and Carboniferous systems which attain a
great thickness in other parts of England are
missing.

The accompanying map indicates roughly the geological nature of the south-east portion of England.

FIG. 4.

The Wealden area consists in the middle mainly of sands (Hastings sand) which are surrounded by a zone of·clay (gault clay) on the three sides where it adjoins the chalk.

The Cretaceous area consists of chalk, and (on the side adjoining the Wealden) of chalk marl.

The Eocene strata consist of clay (London clay) associated in many parts with sand (Woolwich and Reading beds, &c.).

The underground sequence of these strata is indicated by the well section of Fig. 3, and the probable

distribution of the beds which it penetrates is shown
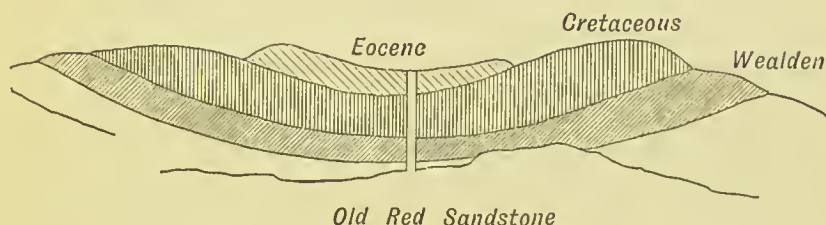in the accompanying diagram.

FIG. 5.

Enough has been said to show the enormous
varieties of rock to be found in Great Britain alone.

The great differences which exist in the properties
of these various formations are at once impressed
upon the eye when we contrast the vegetation which
they naturally support ; oak forests abound on the
weald clay and the kimmeridge clay ; the beech
thrives upon the oolite limestones and the chalk ; the
orchards of the new and old red sandstone are re-
nowned ; while the serpentine of the Lizard peninsula
is barren save for the Cornish heath which grows
there and in no other part of the British Isles.

CHAPTER I

HUMUS AND MICRO-ORGANISMS

> " Not so thick swarmed once the soil
> Bedropt with blood of Gorgon."
> —MILTON.

THE SURFACE SOIL

THE soil or surface of the ground at any place con-
sists mainly of altered and decomposed rock derived
from the underlying stratum or subsoil and will thus
vary very greatly in its composition. It is always
mixed with a large amount of **humus**. In inhabited
regions the soil is partly " made soil," consisting of
road material and all the waste products of human life
and buildings.

In most places, a certain amount of the surface-soil
consists of gravelly and sandy detritus, known as
" rainwash ;" and a mixed " alluvial deposit" due to
the action of running water which has swept away
material from surrounding districts invariably enters
into the composition of the surface-soil.

Beneath the surface-soil is to be found rubbly

material known as "brash" which consists simply of broken and partly decomposed masses or small pieces of the subsoil; this "brash" rests upon the subsoil proper.

The surface-soil is almost always derived from the subsoil by "weathering," that is to say, by the long-continued action of frost, rain &c. which breaks up the rock first into brash and then into mud, clay, sand and the other soil constituents. The nature of the surface-soil depends therefore in general upon the subsoil, and the latter is of primary importance in all questions relating to water supply and temperature of the ground. Only in case of boulder clay and recent alluvial deposits is the soil to any large extent independent of the nature of the subsoil.

The important part which is played by earthworms in forming the soil must not be forgotten. Darwin states that the vegetable mould which covers the surface of the land has all passed many times through their bodies, and that mould differs from the subsoil in the absence of fragments or particles of stone which are too large to pass through the bodies of earthworms.

To quote his own words "When we behold a turf-covered expanse we should remember that its smoothness on which so much of its beauty depends is mainly due to all the inequalities having been slowly levelled by worms. It is a marvellous reflection that the whole of the superficial mould over any such expanse has passed and will again pass every few years through the bodies of worms."

We wish to lay great stress on the fact that the soil is composed partly of inorganic matter derived from the subsoil by the process of weathering, and partly of the products of decomposition of animal and vegetable matter.

With regard to the exact composition of humus, very little is known. So many things contribute to its formation, among which we may mention the decay of plants, the casts of earthworms, droppings and carcases of animals, and the exuviæ of insects. Chemists have attempted, by means of solvents, to separate humus products into their constituent parts, and certain acids have been found, some of which, such as Crenic Acid ($C_{12}H_{12}O_8$) are soluble in both water and alkalies ; others, such as Humic Acid ($C_{21}H_{24}O_{12}.3H_2O$), being insoluble in water but soluble in alkalies ; whilst others again, such as Ulmic Acid ($C_{40}H_{28}O_{12}.H_2O$) are insoluble in both water and alkalies. The colour of humus is said to depend upon the nature of the acid present, ulmic acid characterising brown, and humic acid black mould.

The acid reaction of the soil is generally due to carbon dioxide, but it may be due to an excess of free acids, such as humic, in which case the soil appears to be unsuitable for vegetable growth ; only after the application of lime, marl &c., can such acid humus be rendered suitable for the development of plants.

Peat. In temperate and arctic climates large areas are sometimes covered by masses of vegetable matter which have resulted from the decomposition of bog mosses and other marsh plants. This varies in

thickness from two to thirty feet, and is a spongy material of a light brown colour on the surface, but darker and more earthy at greater depths. Lignite and coal both appear to have originated as peaty deposits. In spite of its vegetable origin peat, so far from encouraging putrefactive processes, is remarkably free from organic impurities, and actually exerts a preservative influence upon animal remains imbedded therein. A remarkable illustration of this fact is afforded by the so-called " bog butter " found in the Irish peat bogs, formerly supposed to be a mineral but now thought to be true butter which was stored in the peat for the purpose of preservation.

MICRO-ORGANISMS IN THE SOIL

If we consider the changes that are constantly taking place on the surface of the ground—how vegetable matter is ever decaying and becoming incorporated with the soil—how animal matter in its many different forms is continually undergoing putrefaction and decomposition, we shall realise to some extent the endless variety of these never-ceasing processes, and the important part they play in nature. Thanks to bacteriologists we are now acquainted with the agencies by means of which these changes are carried on. We know that they depend upon the life and growth of certain minute plants which are usually called **micro-organisms** or **bacteria**. Without them it is impossible for putrefaction, decomposition, fermentation and the like processes to take place. We

should therefore naturally expect the ground to con-
tain an enormous number of these vegetable *micro-*
phytes, and indeed we find that the superficial layers
of the soil are crowded with them.   Thus Miguel
estimated that a gramme of soil from the rue de
Rennes in Paris, contained no less than 1,300,000
germs.   These micro-organisms rapidly fall off in
number as we descend below the surface, and the
subsoil is practically free from them at depths ex-
ceeding twelve feet.

Some of the most interesting of those with whose
life processes we are at all acquainted are the
Nitrifying Bacteria.   These organisms universally
distributed, at any rate on cultivated land, decompose
organic matter into its simplest constituents, whereby
vegetation is enabled to assimilate the elements
necessary for growth.   Plants cannot obtain their
supply of nitrogen directly from complex organic
bodies, but by the life-processes of these bacteria
organic matter is split up, its nitrogen becomes con-
verted into ammonia and thence into nitrites, and
eventually nitrates are produced, in which form plants
take up their nitrogen.   If we may generalise from
experiments, earth free from bacteria or their spores
(*sterilized* earth) appears to be quite unfit for the
development of plants.

Schlössing and Muntz first showed that nitrification
was probably due to bacteria, and most of our know-
ledge on the subject is due to their researches.

It appears that wherever the oxygen of the air
penetrates the soil, these nitrifying organisms are

constantly at work decomposing organic matter, both animal and vegetable, and thereby bringing about the production of carbon dioxide, water and nitrous acid. This property of splitting up complex nitrogenous bodies leading to the formation of nitrites is characteristic of these bacteria. If they are introduced into a liquid *cultivation*, nitrites in quantity are found but no nitrates; yet on examining the soil nitrites are found in very small quantity, but nitrates in large amount. In what way is this conversion of nitrites into nitrates, which must be constantly taking place in the soil, brought about? One would naturally imagine, knowing how readily nitrous acid absorbs oxygen and becomes converted into nitric acid, that the process is simply one of oxidation, since oxygen is always present in the air of the soil, but Muntz's experiments show that this is not the case.

As we shall see in a later chapter, owing to the incessant decomposition of organic matter going on in the ground, carbon dioxide forms a large proportion of the ground air. Now if large quantities of carbon dioxide are passed through a solution of nitrite of lime, nitrous acid is set at liberty and carbonate of lime is formed. If oxygen is passed through as well as carbon dioxide, the oxygen combines with the nitrous acid, which is set free by the carbon dioxide, and nitric acid is produced; in nature this forms nitrates by combining with bases in the soil.

Hence, whilst *nitrification* is due entirely to the nitrifying bacteria, *nitration*, *i.e.* the further conver-

sion of the nitrites into nitrates, is entirely a chemical process brought about by the action of carbon dioxide and oxygen present in the ground air and does not depend on the life-processes of any organisms.

Recent researches of Warrington and Wino-grawdski tend to show that this statement may not be universally true, since they seem to have succeeded in isolating a ferment which has the power of converting nitrites into nitrates.

The nitrifying power of different soils varies with the nature of the soil. Alkalinity, aeration, moisture and a temperature of about 36°C. (96°F.) are the most favourable conditions. Alkalinity is, as a rule, due to the salts of lime and potash, while suitable aeration and moisture are best provided by a loose porous soil.

We have dealt with the nitrifying organisms at some length because they illustrate the fact that processes constantly taking place in the soil, and formerly supposed to be entirely of an inorganic nature, are in reality due to the life processes of vegetable microphytes. In this connection we may refer the reader to the remarks on p. 21 concerning the weathering of rocks.

Undoubtedly most of the bacterial forms inhabiting the superficial layers of the soil are **non-pathogenic,** that is to say quite incapable of causing disease in man ; nevertheless it has within the last few years been shown that *certain* **pathogenic** micro-organisms, that is to say organisms which produce disease and which can live in the tissues of the body, have their

primary habitat in the superficial layers of the soil ; whilst others are capable, at any rate during part of their existence, of finding a suitable nidus there ; and in this way a relation exists between the soil and certain diseases.

These pathogenic organisms belong to the group of Schizomycetes or Fission-fungi, one of the three great classes into which micro-organisms are divided by bacteriologists.

Certain conditions are essential for the life and growth of the schizomycetes. In the first place some *pabulum* containing carbon and nitrogen must be present. Being devoid of chlorophyll they are apparently unable to obtain their supply of carbon from the carbon dioxide of the air, but only from organic bodies which contain this element. The nitrogen also is derived from organic compounds.

The presence of certain inorganic salts, such as phosphates and the salts of potassium and sodium, appears to be desirable.

But other conditions besides presence or absence of food are necessary to their existence, and one of the chief is *moisture*. Without this, non-spore-bearing organisms are killed, and the spores of spore-bearing organisms although not killed are nevertheless prevented from germinating. In addition to food and moisture there must be a *favourable temperature* and an *absence of inimical compounds*.

It is possible that some of the organisms in the soil may, as a result of their life processes, give rise to substances which are inimical to certain of the

pathogenic organisms. Again, an excess of free acids, such as humic acid in the soil, may act as a poison.

Some of the schizomycetes are unable to form spores unless they have a supply of free oxygen; such organisms are called *aerobic;* anthrax is a good example. Others, like the bacillus of malignant œdema, are capable of deriving oxygen from complex bodies, and can therefore form spores when deprived of air; these are called *anaerobic* organisms.

Under certain circumstances, therefore, it would appear possible that some, at any rate, of the pathogenic organisms find in the soil conditions favourable to their existence. At the same time there are many agencies at work which constantly tend to nullify these necessary conditions.

Assuming that favourable conditions are present, we have to consider in what ways pathogenic organisms in the soil may be a source of danger to the human subject. Now, bacteria can gain an entrance into the system either by direct *inoculation* (as in tetanus), or by *ingestion* into the alimentary canal (as in enteric fever), or by *inhalation* into the lungs (as in phthisis).

Some diseases however can be communicated to man in more than one of these ways; anthrax for example by inoculation causes malignant pustule, introduction into the alimentary canal produces a form of septicæmia, and lastly woolsorters' disease is the result of inhalation.

Before bacteria or their spores can be inhaled it is obvious that they must become air-borne, and we

shall in a later chapter discuss how this may be brought about by means of ground air currents.

Ingestion into the alimentary canal implies previous contamination of food or drink; inoculation sufficiently explains itself.

We now pass on to consider seriatim certain diseases possibly dependent on micro-organisms existing in the soil.

EPIDEMIC INFANTILE DIARRHŒA

Dr. Ballard, of the Local Government Board, as a result of his exhaustive inquiry, concludes that the essential cause of **epidemic infantile diarrhœa** exists in the superficial layers of the soil where it is connected with the life processes of micro-organisms not yet satisfactorily isolated. Their pabulum is the dead organic matter in the humus, their vitality depending on this together with heat and moisture. Under certain circumstances these organisms appear to be capable of becoming air-borne; they then fix upon non-living organic matter, such as milk, and are thus taken into the human alimentary canal. The virulent poisons which are produced as a result of their metabolism set up diarrhœa.

Epidemic infantile diarrhœa occurs at all seasons, but always increases in the summer months. When the 4-*foot earth thermometer* reaches a temperature of about 13° C. (56° F.) no matter what the temperature of the air, the rise of diarrhœal mortality commences, and the mortality reaches its maximum with the

maximum temperature of the 4-foot earth ther-
mometer, the decline of the mortality coinciding
with the decline of the temperature of the 4-foot
earth thermometer.

The temperature of the more superficial layers of
the earth is subsidiary—the heat apparently must
penetrate to a depth of at least four feet.

After a heavy rainfall, when the ground is saturated,
the diarrhœal mortality is diminished, and the same
result occurs if the ground is too dry. There must
be a certain degree of moisture, but it must not be
excessive.

We should expect therefore to find that loose and
porous soils such as sand and deep mould, which are
kept moist and aerated, and which rapidly become
well heated, are favourable to a high diarrhœal
mortality. Moreover, such soils are more likely to
be polluted by organic matter from defective drains
or cesspools; and further, currents of ground air
constantly rising may carry the organisms out of the
soil into the atmosphere.

Thus the mortality from infantile diarrhœa is very
high at Leicester, where the houses are built on
sandstone, but almost nil on the granite and slate
rocks of Cornwall.

Many observers will agree with Dr. Ballard in
considering that decomposing and fermenting food,
especially milk, may bring about epidemic diarrhœa
and since it is impossible for decomposition and
fermentation to take place without bacteria, they
may be regarded as the essential cause of the disease ; '

but whether or not sufficient evidence has been brought forward to show that these organisms as a rule exist in the soil or to allow of even a working hypothesis being formed on these lines is open to a good deal of doubt.

ANTHRAX

Koch has conclusively shown that the gastric juice kills **anthrax bacilli** but not the spores, and hence that anthrax is only harmful to man and animals when in a spore condition.

Now anthrax bacilli never form spores within the living body ; for this there must be a free supply of oxygen and a certain temperature ; hence if the body of an animal that has died of anthrax is buried *unopened*, the source of danger will be removed, all the anthrax bacilli being killed by putrefactive bacilli in from five to ten days.

Unfortunately when an animal dies of anthrax, the carcase as a rule is dragged along the ground before burial ; meanwhile, owing to effusion (always present in these cases) pools of fluid *crowded* with bacilli are formed on the ground.

The bacilli being exposed to air form spores which withstand heat and cold, dryness and moisture. They are extremely resistant, and can exist for years in the spore state.

Spores and bacilli are washed by rain all over the fields ; there is continual multiplication and spore formation, and in this way miles of land may become infected ; we have an example in the Russian Steppes.

Marshy and damp soils containing much humus appear to be most favourable for the spread of anthrax, and cattle and sheep feeding in such places may take the spores into their intestinal canal ; and the hides and carcases of such animals may become a source of infection to man in the ways indicated on p. 36.

Anthrax bacilli when present in the soil are always originally derived from a previous case of anthrax.

MALIGNANT ŒDEMA

Pasteur brought forward a theory that when an animal which has died of anthrax is buried, earthworms bring the spores to the surface and bacilli develop there and can be found and cultivated. It has subsequently been shown that what Pasteur found were the bacilli of **malignant œdema.**

These are anaerobic organisms and when grown on sterilized gelatine produce characteristic gas bubbles and do not, like anthrax, liquefy the gelatine ; they are found in garden earth, especially if it has been recently manured, and are possibly the cause of hospital gangrene.

TETANUS

The organisms which produce **tetanus** are, like those of malignant œdema, anaerobic—the bacilli, but not the spores, being killed by exposure to oxygen.

These bacilli have been found in garden soil, in
earth from a horse's foot, in dust from houses &c.,
and have been cultivated within the last few years.
Moreover earth or stable refuse injected into guinea-
pigs and mice causes symptoms which are identical
with those of tetanus.

We have sufficient proof that the soil is the
primary habitat of the tetanus organisms. The
researches and experiments of M. Bossano show
that they are very widely distributed in the soil,
the presence of organic matter being the all-import-
ant factor. Climate and meteorological conditions
have but little influence on the life of these
organisms.

Tetanus may be compared with diphtheria and is
not a true infective disease. The organisms never
pass beyond the seat of inoculation. By their life
and growth they produce a virulent poison (tetanine)
which is absorbed into the blood, and by its action on
the nervous system gives rise to the convulsions which
are characteristic of the disease.

It is a matter of popular knowledge that tetanus
is more common after wounds on the hands than on
any other part of the body. The reason is obvious :
wounds and abrasions of exposed parts admit of the
entrance of the specific bacillus. For example, a
gardener whose hands are always more or less
covered with mould, scratches his thumb against a
rusty nail, tetanus follows and is of course attributed
to the rusty nail, whereas in reality this is but the
means by which the bacilli gain entrance. It is of

course quite possible that a rusty nail may itself be covered with dust containing spores of the tetanus bacillus.

Tetanus is more common amongst children who play about without shoes and stockings than amongst adults. Gardeners and grooms are especially liable to it for the reasons already given.

We may compare tetanus with hydrophobia. The percentage of cases of hydrophobia in the human subject following bites by rabid dogs is much greater for bites on exposed parts than in those cases in which the dog's teeth penetrate clothing before reaching the skin. It is obvious that in the latter the virus is generally wiped off by the clothes. For a similar reason the tetanus bacillus is less likely to gain an entrance through a wound on the knee than on the palm of the hand.

It is however absurd to suppose that tetanus always supervenes after inoculation with the tetanus bacillus. It only occurs (as hydrophobia after bite of a rabid dog) in a very small percentage of cases. We have seen that the bacilli never pass beyond the seat of inoculation, so that until they have had time to produce "tetanine" the disease is strictly local, and may be removed by local means, such as thorough cleansing of the wound, more especially by the use of some germicide.

Many savage tribes prepare their poisoned weapons by smearing them with mud, which they know has some deadly property. It has been suggested that this mud may contain the bacilli of tetanus or

of malignant œdema, since symptoms of tetanus or of pyæmia are said to follow wounds produced by such weapons.

MALARIA

The word "**malaria**" includes many varieties of a group of diseases which resemble each other in the main, though possibly the poison may not be of exactly the same nature in all cases.

We have some evidence that the superficial layers of the soil are concerned in the etiology of malaria. Tommasi-Crudeli and Klebs have succeeded in cultivating on various media, a distinctive bacillus which they obtained from the highly malarious soil of the Roman Campagna, and they believe to be pathogenic. This bacillus malariæ has been shown to form spores.

On the other hand, Marchiafava and Celli have found in the red blood-corpuscles of patients suffering from malaria minute bodies which they term Hæmoplasmodium Malariæ, which have not at present been found in the soil, nor indeed have they even been cultivated outside the human body.

They are amœboid-like bodies, which appear to separate out the pigment of the red blood corpuscles. The spores which eventually form are found only in the spleen ; these give rise to fresh amœbæ, which pass into the blood and cause renewed fever, the nature of the ague being determined by the rapidity with which these different stages take place ; for example, in quotidian ague all the stages occur in one day.

The soil of the Campagna from which Crudeli and Klebs obtained their bacillus malariæ has little depth and is rich in organic matter. Underlying it are volcanic tuffs and breccias ; during prolonged drought the soil is baked, whilst after heavy rains water rests upon the volcanic rock and saturates the soil.

Malaria appears generally to be associated with excessive moisture of the soil and the presence of organic matter, especially decomposing vegetable matter, but this is by no means universally the case.

Saturation with moisture may be brought about in a variety of ways. The soil may be comparatively impervious and retain moisture, or may be shallow and porous, with an impermeable substratum leading to a high level of the ground-water ; or again, there may be some obstruction to the outflow of the ground-water ; (ground-water will be fully dealt with in the next chapter). As is well known, subsoil drainage reduces the prevalence of malaria, and the same result may be brought about by the growth of trees and plants, such as eucalyptus globulus, oak-trees and sunflowers, which are capable of absorbing and evaporating from their leaves an enormous quantity of moisture.

Constant complete saturation with salt water appears to be unfavourable to malaria, but marshes which are occasionally overflowed by the sea are often malarious. The following facts which bear very closely on this question have been brought to our notice. In a low-lying valley watered by a tidal

river the point where the water ceased to be brackish corresponded with a well-marked line of demarcation between the malarious and non-malarious parts of the valley. Between this line and the sea, malaria was so prevalent that the farmers always carried quinine in their pockets, whilst on the other side of the line no precautions were ever taken, and there was a complete absence of malarious diseases. It has been suggested that the exhalation of poisonous miasms from organic decomposition due to the salt water killing fresh-water plants and organisms accounts for this, but such theories, apart from any proof, are too vague to be of real value. It is much more probable that alkalinity of the soil due to the brackish water is the important factor.

The mineral constituents of the ground appear to be of little consequence in the causation of malaria, which may be prevalent in soils of such widely different composition as alluvial, sandy or ferruginous soils, and those formed from the weathering of metamorphic rocks.

If we accept the bacterial origin of the disease, and this is a debated point, a malarious soil will depend not on the nature of its inorganic constituents but upon the presence of those conditions which favour the life of the specific organisms and bring about their aerial diffusion.

DIPHTHERIA

We have no actual proof that the true diphtheritic bacillus (Löffler's bacillus) can exist in the superficial

layers of the soil, or become air-borne in sewer gas or
other emanations.

Now although the most usual ways by which
diphtheria is diffused are from person to person or
by means of milk (cows being very susceptible to
diphtheria), yet "sporadic" cases, or those which
start an epidemic, often arise in connection with
organic pollution of the soil ; it may be from a leaky
cesspool or drain, or from piggeries and accumula-
tions of refuse ; moreover, epidemics of diphtheria
have arisen after disturbance of excrement-sodden
earth.   To account for this we may adopt one of
two hypotheses ; either that septic sore-throats
brought on by the inhalation of offensive organic
vapours offer a very suitable nidus for Löffler's
bacilli, or else that these bacilli or their spores are
capable of existing in fetid organic matter in the
soil, and may under certain circumstances become air-
borne.

Dr. Greenhow, of the Medical Department of the
Privy Council, as the result of an extensive inquiry
in 1858, reported that the disease was especially pre-
valent on cold wet soils such as clay, and this was
confirmed by Dr. Airy in 1880.   Constant moisture
of the soil appears to be the chief factor, and a damp
soil, by allowing (unless proper precautions are taken)
structural dampness of dwelling-houses, is generally
admitted to be favourable for the incidence of the
disease, possibly by its influence on the vitality of
the specific organisms.

ENTERIC FEVER (TYPHOID)

There is a probability that the specific organisms of **typhoid fever** can under certain conditions of moisture, temperature and pabulum exist in the soil, but absolute proof is wanting because we do not at present know for certain which is the true bacillus of typhoid fever. Many organisms have been described in connection with typhoid fever ; of these, Gaffky's bacillus (see frontispiece) is the one most generally accepted as being the true typhoid bacillus, but many bacteriologists in this country regard it as a pseudo-bacillus.

Gaffky's bacillus is a motile organism and does not liquefy gelatine as do other motile organisms. Besides being able to exist without a free supply of oxygen (as in the intestines for example) it appears to thrive well in the presence of free oxygen. This organism has been shown to remain active in typhoid excreta for fifteen days.

But it is obvious that until bacteriologists are agreed as to which is the true typhoid bacillus and have studied its methods of growth, &c., we cannot be certain that typhoid organisms can live in the soil. We know, however, for certain that typhoid excreta are infective and that they retain their infective character for some time, even when dried ; and when we consider that in country places typhoid stools are often, after very imperfect disinfection, dug into or simply thrown upon the ground or carried into defective cesspools,

it does not seem altogether unreasonable to suppose that typhoid organisms or their spores can exist in soil polluted with typhoid excreta, and that in this way may be explained outbreaks of typhoid fever otherwise obscure—the poison being introduced into the human alimentary canal by means of con-taminated water or food ; for example, rain might wash some of the poison from the soil into a neighbouring stream from which drinking water is obtained.

We shall in the next chapter give instances of the way in which this may be brought about, and also refer to Pettenkofer's Munich Theory with regard to typhoid fever and the soil.

EPIDEMIC PNEUMONIA

From **pneumonia** cases occurring during an epi-demic at Middlesborough in 1888, and also during an epidemic at Scotter in 1890, Dr. Klein isolated a minute organism, the Bacillus Pneumoniæ. By inoculation the disease could be communicated to mice, and by cultivation the bacillus was recoverable from the morbid tissues of the mice. This bacillus pneumoniæ is possibly the true bacillus and the cause of epidemic pneumonia.

When cultivated artificially the bacillus thrives best if freely exposed to air.

It was clearly shown that a *polluted condition of the soil* was one of the factors concerned in the Scotter epidemics ; the bacillus pneumoniæ perhaps (and

there is evidence in favour of this) being air-borne in emanations from the soil.

It may perhaps appear that we have laid undue stress upon the importance and prevalence of **micro-organisms in the soil,** but the reader will do well to remember that (with the exception of infantile diarrhœa) we have confined our attention to diseases in which the presence of these organisms has been distinctly proved and to which they appear to have a causal relation.   Now there is not the least doubt that the surface soil is absolutely swarming with micro-organisms of different kinds ; most of these are undoubtedly *non-pathogenic*, their function appears to be the work of decomposition and disintegration both organic and inorganic ; the immense importance of such organisms in the ordinary weathering and decay of most rocks has only recently been realised, see p. 20.   Equally certain, however, is it that some of the *pathogenic* organisms have been proved to exist in the soil.

It is surely then of vital importance at the present time, when precautions against these diseases have resolved themselves into attempts to ward off the specific bacteria, that we should regard the soil as the possible habitat of many of these organisms and bear this in mind in our sanitary efforts.   It is true that predisposition to diphtheria, typhoid fever and many such diseases may be induced by a thousand different conditions, such as ill health, debility, adverse climate, diet, heredity &c., but modern research tends to prove

that these are not enough unless the specific bacilli are also present. It is therefore of primary import- ance that they should not be allowed to find a habitat in the soil owing to any laxity in our sanitary regulations. The dragon's teeth sown by Cadmus did not produce a more fatal crop than do the spores of pathogenic organisms when they fall upon favour- able ground.

It must be noted that even if the intimate relation of micro-organisms to disease be doubted or their very existence denied, there are many cases in which the soil is obviously a source of infection whatever may be the reason ; and by as far as possible putting a stop to fouling of the soil with animal organic matter owing to leaky drains, defective cesspits, accumu- lations of refuse and the like, we may hope to reduce the prevalence of many of these diseases.

To realise how little is yet known with regard to both pathogenic and non-pathogenic organisms in the soil is to acknowledge the importance of those discoveries which have already been made, and to feel confident that they have set us on the right path. More advanced knowledge can only be made by the simultaneous study of two subjects—the nature and life-history of the bacteria themselves and the nature of the soil. The latter is a study which will be further developed in the subsequent chapters.

CHAPTER III

THE DISTRIBUTION OF WATER IN THE SOIL

" We next inquire, but softly and by stealth,
   Like conservators of the public health,
   Of epidemic throats, if such there are,
   And coughs and rheums, and phthisic and catarrh."
                                        —COWPER.

RIVERS, SPRINGS AND WELLS

OF the rain-water which falls upon the land, part
sinks into the ground, another part runs off the surface
in the form of **streams and rivers,** and the remainder
passes into the air by evaporation.

If the soil is fairly impervious such as clay or marl
a considerable proportion of the water remains upon
the surface ; this may either be retained by a flat peaty
soil, and give rise to marshes, swamps and bogs, as is
largely the case in Central Ireland and formerly in the
fen country of Eastern England, or it may, where the
superficial soil is hard and not very level, run into
channels and flow away towards the sea.

In hilly country, the streams and rivers run rapidly

E 2

towards the sea, they cut for themselves comparatively narrow channels and carry their sediment away with them ; in plain country, where the rapidity of the stream is less, the sediment sinks to the bottom and is continually deposited to form ever-increasing sheets of **alluvium.** In the soft alluvial plains over which the most sluggish rivers meander, this deposit is sufficient to choke the bed of the stream and causes the river from time to time to alter its course, so that such plains gradually extend in all directions and finally cover enormous areas.

The alluvium of mountainous districts where the rivers are rapid is generally coarser than in plain country where the slow stream can only carry fine particles. Almost all the greater rivers of England flow through large tracts of country covered by gravel and alluvial deposits of recent date. The alluvium at the Tilbury Dock consisting of mud, clay, peat and gravel was found to be no less than fifty-seven feet in thickness.

We now return to the water which sinks into the ground through a more or less permeable surface soil ; a certain amount of this is arrested and absorbed by the roots of plants and is subsequently evaporated from their leaves, but the greater part percolates through the fissures and crevices of the underlying rocks, until it reaches a more or less impermeable stratum ; here it must either rest, or, if the surface is inclined, it will flow down to find an outlet at some lower level.

As an illustration of the extent to which percolation

takes place we may instance the streams in the
Cotswold hills whose volume has been found to
diminish considerably when they pass over porous
strata.

The subsoil water which creeps over the surface
of an impermeable stratum finally finds an outlet
at the outcrop of this stratum and then issues as
a **spring.** For example the fuller's earth, a marly
clay underlying the oolite limestone, throws out
copious springs in the neighbourhood of Bath ; the
jurassic Portland sands yield water thrown out by
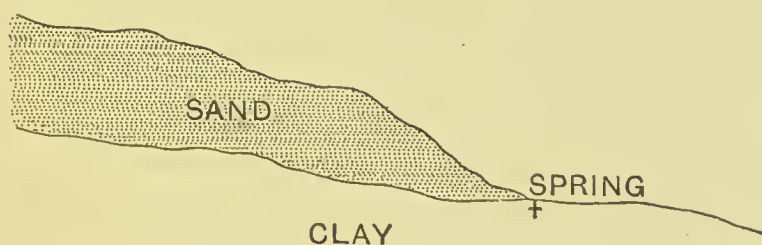
FIG. 6.

Spring thrown out at the outcrop of clay underlying a water-bearing
stratum of sand.

the underlying Kimmeridge clay which is not itself
a water-bearing stratum ; and the chalk marl simi-
larly prevents the escape of the water which per-
meates the chalk. Spring-water has, therefore, always
undergone a certain amount of filtration in its passage
through the overlying porous strata, and only differs
from **well-water** in issuing by a natural instead of
an artificial outlet ; but for this very reason it is
water which has been in constant movement, and has
not remained stagnant in subterranean reservoirs.

Finally, the supplies of water from all the springs of any large area enclosed by high ground unite with the superficial rain-water to form streams and rivers. We confine our attention for the present to the water below the surface.

Little is known as to the depth to which the underground water percolates or as to the causes which co-operate to check its downward course, but it is invariably found that below a certain depth the rocks are completely permeated by water. Below this level a condition prevails in which all the interstices of the soil are filled with a continuous sheet of water to the exclusion of air ; this is known as **ground-water.** Above this level the soil contains more or less moisture.

We have therefore to distinguish between :

(A) **ground water**
(B) **moisture of soil.**

(A) GROUND OR SUBSOIL WATER

From what has been said above, it is clear that there is an underground water-level just as there is a water-level in a lake or sea ; and in any district this level is marked by the depth at which the water stands in the wells of the district.

Although the ground-water is a continuous subterranean sheet, its upper surface is not usually horizontal but varies with the nature of the soil and other local conditions. The accompanying section,

for which we are greatly in-
debted to Prof. Prestwich,
F.R.S., shows very clearly
the distribution of the ground-
water in the neighbourhood
of Oxford : it illustrates the
manner in which the level
of the ground-water may
stand above that of the
neighbouring rivers ; the dot-
ted portion represents the
water-bearing gravel which
rests upon the impermeable
Oxford clay ; and in the bed
of gravel on which the town
stands the water level (in-
dicated by dotted lines) is
distinctly dome-shaped.

Again, the ground-water is
in constant movement to-
wards the sea or nearest
watercourses ; at Munich, for
instance, Pettenkofer has esti-
mated that it moves towards
the Isar at the rate of fifteen
feet daily ; at Berlin, on the
contrary, the movement of
the ground-water towards
the Spree is very slight, and
in some places almost nil.

Not only does the ground-

Fig. 7.

Valley of the Cherwell

OXFORD

GRAVEL

Valley of the Isis or Thames

ALLUVIAL CLAY OVER GRAVEL

OXFORD CLAY

Walker & Boutall sc.
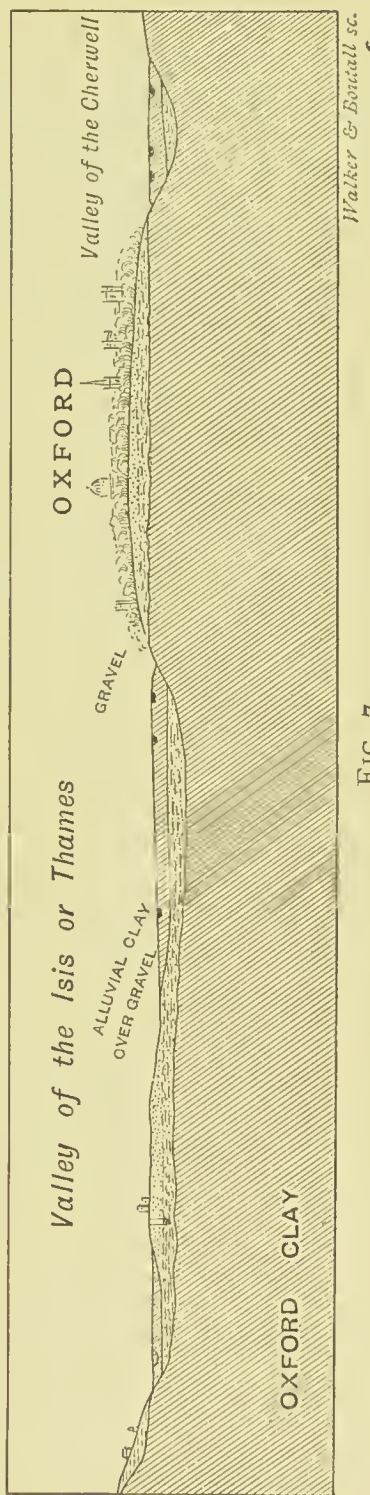
water move in a *lateral* direction, but it also *rises and falls* to a considerable extent with changes of the season, and with certain variations of the local conditions.

This, as we shall presently see, may be a matter of great hygienic importance.

At Munich there is a difference of ten feet between the highest and lowest levels during the year.

As regards the average ground-water level, this varies in different soils and depends largely upon the geological configuration of the district. It may be only a few feet below the surface or even at the ground-level, as in marshy districts, or it may be several hundreds of feet below the surface ; this will depend mainly upon the depth at which there is an impermeable stratum to hold the water. If in any district there is reason to suppose from the geology of the surrounding country, that clay or some other impervious stratum exists at a comparatively slight depth below the surface and underlies a porous stratum, it may reasonably be expected that the porous rock will yield water if a well be sunk into it. This is usually the case, for instance, with the greensand. which overlies the Gault clay and is a valuable source of water in England.

In most regions then we have to take into account not only the rivers which flow over the surface of the country, but those equally important and even more extensive underground rivers which are flowing in various directions, though with a velocity far less than that of the overground rivers, and are subject to

regular oscillations of level. From these are obtained our chief water supplies ; and they must also exert a very considerable direct influence upon the hygienic character of the district. A possible action which they may exert has been studied by Pettenkofer.

PETTENKOFER'S MUNICH THEORY

This theory may be briefly stated as follows:

The maximum of the typhoid mortality curve corresponds to the minimum of the ground-water level.

When the wells are low, the highest mortality —and therefore presumably the greatest number of cases occur. When the water in the wells stands high, the number of deaths from typhoid is small, so that there is a direct relation between the sinking of the ground-water and outbreaks of typhoid fever.

This is well illustrated by the chart, Figure 8, showing roughly the relations between height of ground-water and deaths from enteric fever at Munich in 1872. In this and the succeeding figure the continuous curve rises with the number of deaths and a rise in the dotted line represents a rise of water in the wells.

Pettenkofer considers that the disease is communicated by air-borne germs and that certain stages in their development beneath the soil are facilitated or retarded by the variations in moisture due to the rise and fall of the ground-water.

The relation between the height of the ground-water and deaths from enteric fever at Zurich for the same year, as will be seen by the chart, Figure 9 does not support Pettenkofer's theory—in this in-

-------- *Level of Ground Water*

———————— *No: of deaths from Enteric Fever*

MUNICH 1872.
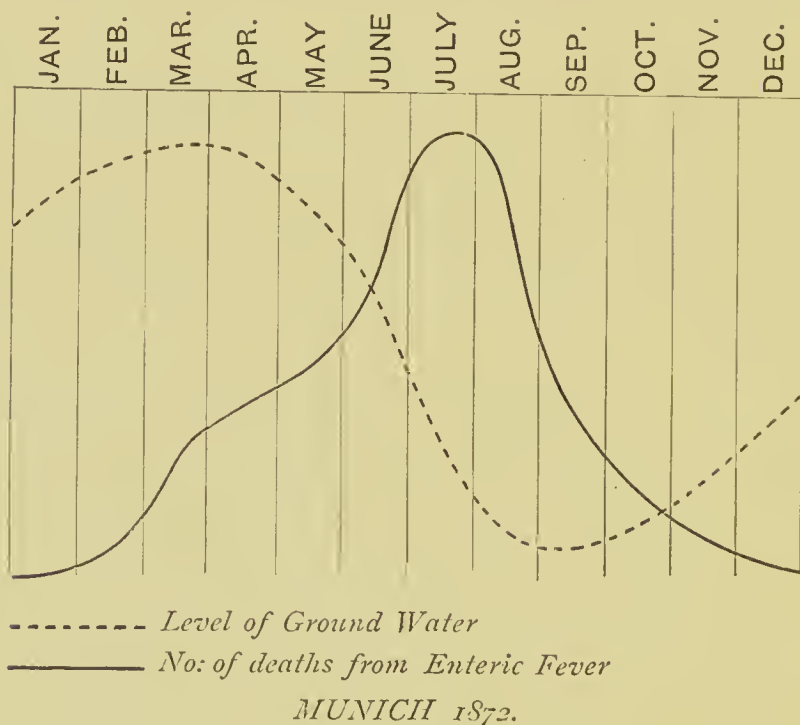
FIG. 8.

stance the maximum height of the ground-water coincides with that of the mortality curve.

In this country Pettenkofer's observations have not been confirmed nor his explanations generally accepted. In some districts where the range of fluctuation of the ground-water is only a few inches, outbreaks of typhoid fever have nevertheless occurred.

Moreover, epidemics of typhoid have been sometimes associated with high ground-water periods.

------- Level of Ground Water
———— No: of deaths from Enteric Fever
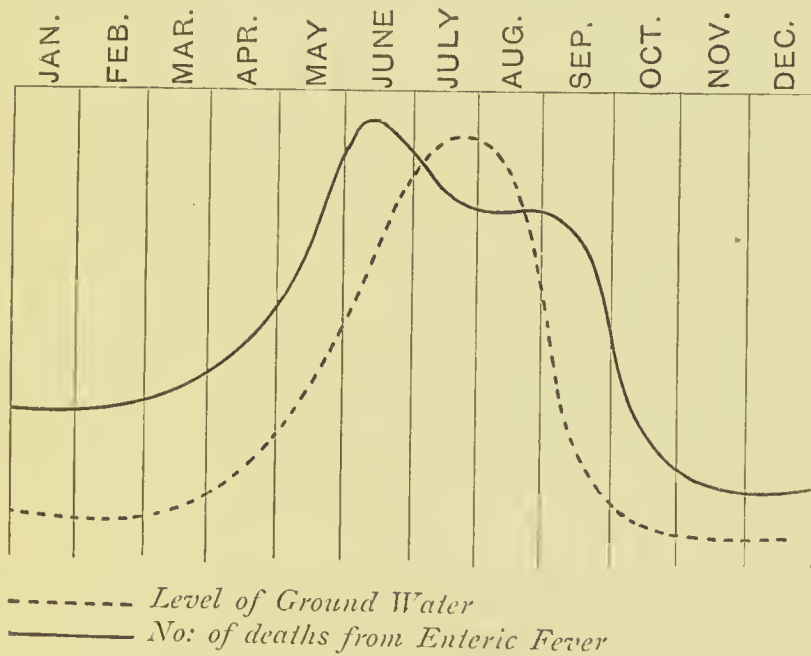
ZURICH. 1872.

FIG. 9.

It should be mentioned that Pettenkofer holds much the same views with regard to cholera and the ground-water.

GROUND WATER AND ENTERIC FEVER

There is overwhelming evidence to prove that the most *usual* cause of **typhoid fever epidemics** in this country is the poisoning of drinking-water with typhoid fever stools.

Now the movements of the ground-water may in

various ways bring about the contamination of wells from which drinking water is obtained and it is possible that some such explanation accounts for any apparent connection that there may be between fluctuation of the ground-water and epidemics of typhoid fever.

We have already stated that the ground-water is always moving laterally in the direction of its natural

Sand

Level of
Ground Water

Sand

Clay

Flow to-outlet
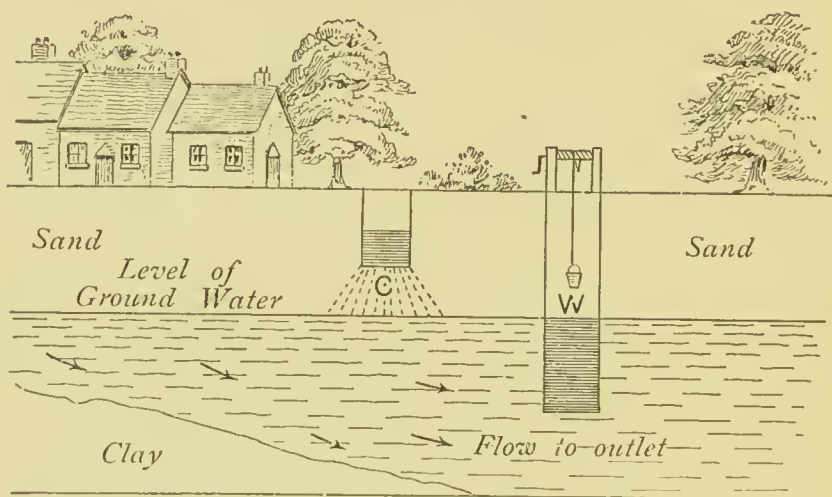
FIG. 10.

outlet. If a well is situated in a porous soil close to a leaky cesspool, and between it and the outlet of the ground-water, it is obvious that the well may become polluted with sewage as shown in the accompanying diagram. It will of course be understood that this and the following figures are merely diagrammatic representations.

If there happens to be a case of typhoid fever in a house which drains into the cesspool, and no pre-

cautions be taken for the *proper* disinfection of the excreta—or if there be a "masked" case of typhoid —the patient going about as usual and quite unaware of the serious nature of his illness—the cesspool may contain the specific poison of typhoid fever, which, as we have seen, may pollute the well and thus give rise to an outbreak.

If, however, the leaking cesspool is situated be-
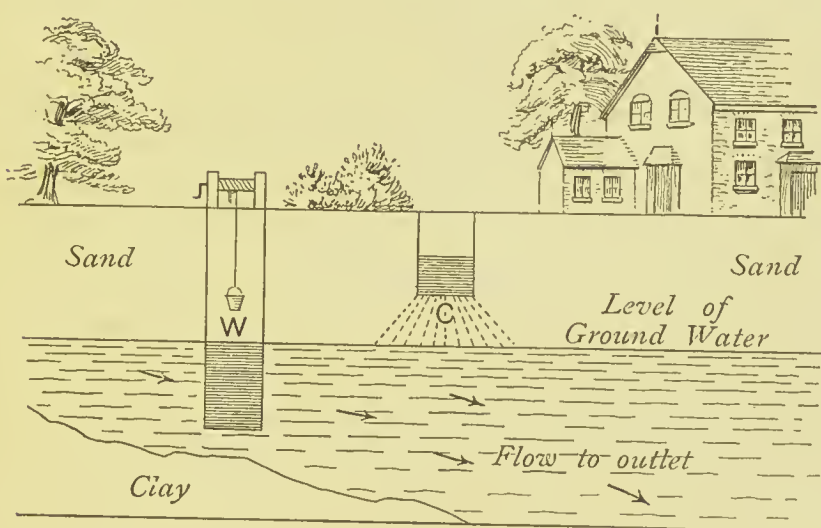
FIG. 11.

tween the well and the natural outlet of the ground-water there is no chance of pollution from the *lateral* flow, as is shown in Figure 11.

But under certain circumstances a well drains an area surrounding it. If, for example, a large amount of water is pumped up from a well, water rushes in both from above and below to supply its place. The area drained varies in different soils being much wider for porous than for non-porous soils. If a

leaky cesspool is situated anywhere within the area
drained by the well—the water may become pol-
luted with specific poison ; see Figure 12.

Or again, if the rock is naturally fissured as is
often the case with limestone, or if there be simply a
crack leading to the ground-water, dangerous matter
may pass into the ground in the way indicated in the
figure, and so pollute the well water.   Thoinot and

| W. | *Well* | M. | *Manure Heap* |
| C. | *Cesspool (bricked)* | A.B. | *Crack in Limestone* |
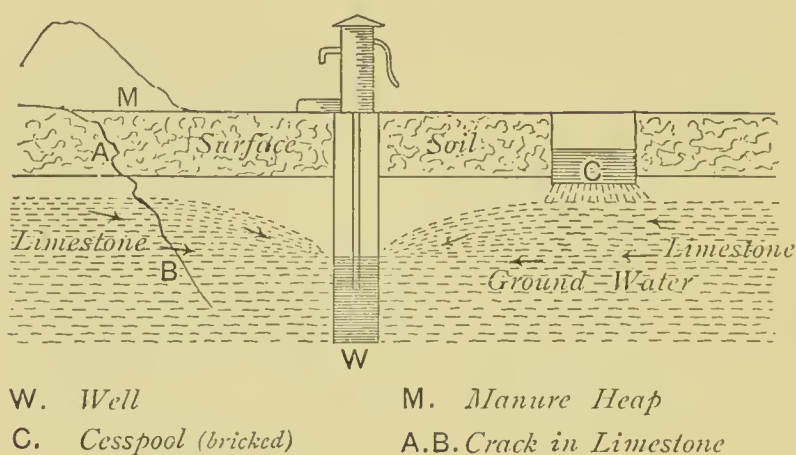
Fig. 12.

Brouardel traced an outbreak of typhoid fever at
Havre to pollution by manure of water which passed
through as much as twenty-five metres of chalk to a
clay substratum and appeared at the outcrop as a
spring at Catillon.

This indicates clearly that, contrary to the general
impression, typhoid excreta may be greatly diluted
and may be filtered through a great thickness of soil
without losing their infective properties.

If the ground-water always stood at the same level

pollution of wells might take place in the two ways indicated above. But it is constantly changing its level and this fluctuation adds considerably to the chances of pollution. For example, part of the contents of a cesspool might soak into the ground but not reach the ground-water at all, or only after considerable filtration ; but directly the ground-water rose to a sufficient height pollution would take place. In many other ways fluctuation may add to the risk of pollution.

Hence, a wide range of fluctuation is the least desirable. With a uniformly high or uniformly low ground-water there is less chance of pollution of wells.

A cesspool in stiff clay soil is much less likely to be defective than one that is simply backed with bricks in a porous soil. The fact that in many districts cesspools are only emptied out very occasionally is proof positive that their contents are constantly soaking into the ground.

As a typical instance of what is so frequently taking place, we quote from a report of Dr. Richmond (published in the journal of the Society of Medical Officers of Health for August 1892) on an outbreak of typhoid fever at Hatfield Broad Oak.

" In my report to the Sanitary authority, I stated as my opinion that the pollution of the water was due to saturation of the soil with offensive matter from the want of efficient drainage in the village, the multitude and bad construction of the cesspits, and the improper disposal of house refuse. The

gardens at the rear of the cottages contain numerous
cesspits which give rise to foul odours, and allow of
percolation around them, owing to the length of time
they remain unemptied, and their leaky condition.
It is evident that the pollution of the water must be
a constant one. Until efficient means have been taken
to alter the present unsatisfactory condition of the
village, outbreaks of typhoid fever must from time
to time occur."

(B). MOISTURE OF THE SOIL, ABSORPTION AND PERMEABILITY

The upper layers of the soil above the level of the
ground-water are "moist," that is to say their inter-
stices contain both air and water; this water is
derived from above and also from below. The rain-
water and the leakage from rivers and lakes perco-
late downwards; but at the same time subterranean
water constantly finds its way towards the surface,
rising through fissures, crevices and cracks of the
over-lying rocks.

The subterranean water doubtless rises not only
by hydrostatic pressure, which urges it to regain
its former level, but by the action of capillary force.

The height to which water is raised by **capillarity**
has been estimated, as

  30 centimetres in sands.
  60 „ „ calcareo-argillaceous soils.
  150 „ „ clays and compact marls.

and still more in vegetable soils (Daubrée).

It has been found that in the superficial soil, the capillary action is greatest for clay and is less for the other varieties in the following order—humus, sand, gypsum and chalk.

On the other hand the capillary action is most rapid for sandy soils, and is less for the others in the order—clay, peat and chalk.

All soils, even the most impermeable, are capable of taking up and retaining a certain amount of moisture, and the dampness of the soil will depend upon its **absorptive power**. A distinction must be drawn between the permeability and the absorptive power of a soil; a permeable soil transmits the moisture and contributes to the supply of the ground-water; an absorptive soil retains the moisture.

The term "absorptive" is generally somewhat loosely used and requires more precise definition. The action of the soil in regard to water is in reality of a threefold nature; it may transmit moisture as wine is transmitted by a strainer; it may imbibe the moisture just as ink is soaked up by blotting paper; and it may hold or be saturated by water as a sponge immersed in water is saturated by liquid which flows from it when the sponge is lifted out. Thus we have to distinguish between the *permeability*, the *imbibition* and the *saturation* of a rock; the amount of surface water which percolates through the soil depends upon the permeability; the amount retained as moisture of the soil depends upon the imbibition; the amount which can be held by the subsoil as ground-water depends upon the saturation. Generally

F

speaking the distribution of the subsoil water varies
with these three factors.

The water of imbibition is sometimes known as
" Quarry water."

Delesse found that

100 grams of		Marl will imbibe		28·0 grams of water.		
,,	,,	Clay	,,	19·6	,,	,,
,,	,,	Chalk	,,	19·3	,,	,,
,,	,,	Granite	,,	0·4	,,	,,

As regards water of saturation Delesse found
that

100 grams of		Sandstone will absorb		29·0 grams of water.		
,,	,,	Chalk	,,	24·1	,,	,,
,,	,,	Slate	,,	0·2	,,	,,
,,	,,	Granite	,,	0·1	,,	,,
,,	,,	Basalt	,,	0·3	,,	,,

The following table summarises a large number
of observations made by Sterry Hunt :

100 grams of		Sandstone will absorb		0·5 to 10·2 grams of water.			
,,	,,	Shale	,,	0·3 to	1·5	,,	,,
,,	,,	Dolomite	,,	0·5 to	5·0	,,	,,
,,	,,	Limestone (Canada)	0·1 to	2·0		,,	,,
,,	,,	,,	(Caen)	15·5 to 16·0		,,	,,

It is stated that humus will retain from 40 to
60 per cent. of water.

Beare has found by experiments upon English
building stones that limestones will absorb from 2
to 13 per cent. of water ; dolomites from $4\frac{1}{2}$ to $7\frac{1}{2}$
per cent. ; sandstones from 3 to 8 per cent. ; granites
from 0·1 to 0·4 per cent.

Expressed as the proportion of the *volume* of the

water taken up to the *volume* of the absorbing soil,
the absorption is for :

Humus	70	per cent.
Clay	51–66	,,
Powdered Limestone	44	,,
Sand	40	,,
Gypsum	38	,,

Absorption being largely a result of capillary
action varies with the coarseness or fineness of the
rock, and is greater for rocks which consist of fine
particles.

Thus powdered quartz has been made to absorb
quantities varying from 7 per cent. by volume to
44·6 per cent., according to the fineness of the
powder.

The value of a rock as a water-bearing stratum
depends mainly upon its capacity of saturation.

Permeability is a very different thing from absorp-
tive power. Sandstones, though not absorptive, are
extremely permeable ; chalk and limestone are per-
meable ; so also are the schists and those igneous
rocks which have a foliated or porous texture.

A rock which possesses a great capacity for im-
bibition cannot be extremely permeable.

It has been found that the percolation through
three feet of clayey gravel covering the chalk at
Rothamsted is about seven inches out of an annual
rainfall of 28·2 inches.

Generally speaking the most permeable soils have
the least storage capacity, although of course a rock,
if sufficiently compact, may be both impermeable and
incapable of much absorption.

Practically the permeability must be estimated by the speed with which percolation takes place. Comparative experiments have shown that water passes most slowly through clay and with increasing rapidity through marls, granitic soil, jurassic loam, loess, limestone, coarse tertiary sand, basaltic soil, loamy marl, fine sand and coarse diluvial sand.

Prestwich found the percolation in cubic inches per hour to be for

Argillaceous sand	1·5
Quartzose sand	5·1
Greensand	3·6
Greensand (coarse)	14·4

Even in permeable strata, like chalk, the rate of transmission is by no means rapid. " On the chalk hills it takes four to six months to pass from the surface to the line of water-level at the depth of 200 feet to 300 feet : so that the heavy rainfall of winter is not felt in the deep springs, and Mr. Beardmore estimates that the maximum effect of a hot dry summer and autumn is not reached until the end of about sixteen months ; or that the storing-power of the chalk is of sixteen months duration." (Prestwich.)

INFLUENCE OF MOISTURE OF THE SOIL ON HEALTH

Having discussed the various ways in which the ground is kept moist and the absorptive and retentive powers of different soils, we naturally pass on to consider in what ways a damp soil may affect the **health** of people living on it.

As we shall see in a later chapter a damp soil is

a cold one and, since it leads to great humidity of the atmosphere, has a considerable influence on the climate of a locality. Although some people feel at their best when the air is heavily laden with moisture and owing to the promotion of expectoration it may be useful in certain diseases, for instance in some cases of bronchitis, nevertheless speaking generally constant excessive moisture of the atmosphere is prejudicial to health, chiefly for the reason that it prevents free evaporation from the skin, and thus increases the liability to " chill taking." From ancient times one of the chief causes of a vast number of diseases such as bronchitis, pneumonia and other morbid conditions of the respiratory tract has been popularly and with reason supposed to be "chill" ; hence damp soils have long been associated with illnesses of which, in addition to those already mentioned, malaria, phthisis and rheumatism are the most important.

In a previous chapter we have dealt at some length with malaria. We shall not refer to this again but pass on to consider phthisis and rheumatism in so far as their prevalence is influenced by moisture of the soil.

PHTHISIS

There can be no doubt that there is a relation between dampness of the soil and the prevalence of **phthisis** but it has probably been considerably over-estimated and its influence is only an indirect one.

As the result of investigations in the south-eastern counties made in conjunction with Dr. Buchanan,

Mr. Whitaker in 1869 stated the following con-
clusions :—

(1) On pervious soils there is less phthisis than on
impervious soils.

(2) On high-lying pervious soils there is less phthisis
than on low-lying pervious soils.

(3) On sloping impervious soils there is less phthisis
than on flat impervious soils.

(4) Artificial removal of subsoil water, alone of
various sanitary works, has largely decreased phthisis.

He also suggests that, whereas shingle tracts
saturated with fresh water conduce to phthisis, as
instanced by the high percentage of cases in the Isle
of Sheppey, the low percentage at Dover indicates
that a similar shingle saturated with salt water is
not pernicious.

It is true that by subsoil drainage of damp soils
the mortality from phthisis has in some places been
greatly reduced.   The following table illustrates this :

	Percentage reduction of deaths from Phthisis after " Drainage "
Salisbury	49 per cent.
Ely	47 ,,
Rugby	43 ,,
Banbury	41 ,,
Worthing	36 ,,
Leicester	32 ,,
Newport (Monmouth)	32 ,,
Macclesfield	31 ,,
Cheltenham	26 ,,
Bristol	22 ,,
Dover	20 ,,
Warwick	19 ,,
Croydon	17 ,,
Cardiff	17 ,,
Merthyr	11 ,,

From a Report to the Privy Council, March 31st, 1868, based
on investigations by Dr. Buchanan.

In other places, however, no such reduction has occurred, and moreover after drainage of some highly malarious districts malaria has disappeared, but diseases of the respiratory organs, especially phthisis, have greatly increased.

Dampness of the soil is simply one of the many factors which are concerned in causing predisposition to the disease. On low-lying damp soils colds and catarrhs of the respiratory tract are more common and more persistent than on high and dry situations and the tubercle bacillus, which is the exciting cause of phthisis, finds a favourable nidus in these cases. It may possibly be that a catarrhal condition is often just sufficient to turn the scale against the resistance of the healthy lung and in favour of the tubercle bacillus.

We know now that phthisis is an infectious disease and that it is usually conveyed by means of sputum from phthisical patients ; the dried sputum contains spores of the tubercle bacilli. These spores are extremely resistant and being inhaled in the form of dust may, if they fall on favourable ground, give rise to the disease. So that whilst dampness of the soil does, in the way we have indicated, tend to lessen the resistance of the individual, it is obvious that many other conditions are of much greater importance ; those, for example, which bring about overcrowding or which cause a fall in wages leading thereby to ill-feeding and general neglect of children, although it may be impossible to determine the exact influence which each factor exercises on the phthisis mortality.

As bearing very closely on this we may mention that in the high mountainous parts of Switzerland phthisis is as a rule almost unknown ; there are many possible reasons for this, the chief being the germicidal action of strong sunlight on the tubercle bacillus, the out-of-door life led by the inhabitants and the absence of hereditary influence. Nevertheless, in some of the deep valleys into which the sun penetrates but little the tubercle bacillus has gained a stronghold ; all the conditions to favour its propagation are present—poverty, heredity and more especially overcrowding in wretched ill-ventilated huts the dust or dirt of which contains in large quantities the spores of the tubercle bacillus.

We may take it then that the diminution of phthisis in some towns we have quoted has not been brought about entirely by subsoil drainage but by improved social and sanitary conditions.

Moreover, owing to improved methods of diagnosis many cases formerly returned as " tuberculous " are now called by some other name—hence phthisis mortality statistics may themselves prove a source of error and lead us to conclude that a reduction in the mortality has taken place whereas in reality there may have been no decline.

RHEUMATISM

The etiology of **rheumatism** is still very obscure. Pathologists all agree that the disease is due to some abnormal condition of the blood and nervous system ;

the swollen joints &c., being local manifestations of a general blood dyscrasia. Several theories have been brought forward to account for the production of the disease, in which dampness of the soil directly or indirectly plays some part ; such theories, for instance, as the following :—

(*a*) Rheumatism is due to the presence in the blood of some poison of the same nature as that of malaria, either miasmatic or of bacterial origin.

(*b*) Chill of the surface of the body causes a disturbance of the central nervous system, the changes resulting being vaso-motor or trophic.

The exciting cause of an attack of acute rheumatism is in the majority of cases exposure to wet and cold ; there is usually a definite history of a chill. But this is by no means always the case, and it would seem that sometimes organic poisons are produced within the body in connection with the intermediate products of nutrition. It is in the former case only that dampness of the soil can exert any influence.

Of the predisposing causes constant exposure to wet and cold is important. The disease is most common among those who are obliged to work out of doors in all weathers, cab-drivers, agricultural labourers, &c. It is more common among males than females because they are, as a rule, more exposed to inclement weather.

Certain districts have deservedly received the name " rheumatic ; " their soil is usually a damp one

and people living on it are more liable to chill than those who live on a dry soil. Moreover, since one of the most important predisposing causes of the disease is inheritance, a family history of rheumatism being obtained in from 20—30 per cent. of cases of acute rheumatism, it is easy to understand how a district in which little or no migration takes place and where the soil is damp and undrained may in a few years become "rheumatic."

In certain districts, however, where the soil is dry, rheumatism is very prevalent. Such apparent anomalies are easily explained ; a damp soil is not indispensable for "chill-taking"; for example, at the time of sunset in the Riviera there is a sudden and rapid lowering of temperature which is dangerous even to the inhabitants.

We have so far mentioned only acute rheumatism. With regard to the chronic forms of the disease some observers have doubted whether the manifestations of rheumatism are ever chronic and it is certain that many diseases formerly called "rheumatic" are now known not to be so. Many cases of so-called chronic rheumatism are in reality cases of **Rheumatoid Arthritis** (rheumatic gout). This disease has nothing to do with gout, and is distinct from rheumatism. In the words of Sir A. R. Garrod it is "an inflammatory affection of the joints not unlike rheumatism in some of its characters but differing materially from it in its pathology." Whilst the predisposing causes of the disease are very numerous—heredity, however, having no very special influence—constant exposure

to wet and cold appears in *some* cases, at any rate, to be the actual exciting cause, and in this way it is possible that a damp undrained soil may have some slight effect, directly or indirectly, in the production of this disease.

CHAPTER IV

THE CONSTITUENTS OF WATER DERIVED FROM THE SOIL

" Purior in vicis aqua tendit rumpere plumbum
  Quam quae per pronum trepidat cum murmure rivum ? "
                                                    —HORACE.

WATER AND ITS CONSTITUENTS

In its passage through the soil and the underlying rocks rain-water abstracts many of their ingredients and becomes charged with a great variety of mineral matter ; this takes place partly by mechanical and partly by chemical means.

In rivers a large proportion of the mineral impurity consists of small particles held in suspension by the water ; this is easily removed by filtration and is not of great importance. But in spring water which has filtered through considerable thicknesses of rock the impurities are present in **solution** and are due to the solvent action of the water upon the mineral constituents of the rocks.

Given sufficient time and also a considerable

pressure and temperature there are very few minerals which are not decomposed or dissolved even by pure water, and in the case of hot deep-seated springs many of the impurities may be derived by the direct solvent action of the water. The solvent action of rain-water is no doubt largely increased by the humus acids which it absorbs.

But ordinary cold springs, such as feed most rivers and contribute to our water supplies, abstract their mineral ingredients from the rocks for the most part in a different way. All rain-water contains a certain proportion of **carbonic acid** derived partly from the atmosphere and to a greater extent from the humus ; now it has been shown by Bischoff and others that most silicates are decomposed by the action of carbonic acid, and that the metallic elements which they contain—the alkaline metals and calcium, magnesium, manganese and iron—pass into solution in the form of soluble carbonates of those metals.

As an instance of the decomposing action of water we may cite the auriferous gravel of California consisting of pebbles of felspar and other silicates which is unaltered at the surface of the ground, whereas below the level of the ground-water it has been converted into an earthy and clayey mass. This gravel is porous and appears to contain much carbonic acid derived from decomposing lignite.

We have seen above that most rocks, whether original igneous rocks or rocks derived from them, consist of silicates of the alkalies, of aluminium, calcium and magnesium ; the carbonates of calcium

and magnesium found in most rivers in consider-
able quantities may be derived partly from this
source by the decomposition of the silicates from
basic rocks.

But water charged with carbonic acid is also
capable of acting directly upon limestone and dolo-
mite and reducing them to soluble bi-carbonates of
calcium and magnesium which pass into solution.
By far the greater part of the calcium and magnesium
carbonates contained in springs and rivers is derived
in this way from the limestone and dolomite which
they have traversed. The other chief mineral im-
purities found in river waters are silica, peroxide
of iron and sulphates and chlorides of calcium,
magnesium, potassium and sodium.

All of these are directly soluble in water: the
chlorides, nitrates and alkaline sulphates with great
ease ; silica, peroxide of iron and the sulphates of
calcium and magnesium only with difficulty.

Silica may then be extracted from all siliceous
rocks ; peroxide of iron from all ferruginous rocks,
especially those which have been exposed to the
weathering and oxidising action of the air ; the
chlorides and sulphates mainly by the direct solution
of salt, gypsum and other chlorides and sulphates
present in sedimentary rocks, where they have prob-
ably been deposited from the sea water or brine
lakes of past geological ages.

Since the qualities of a water are dependent mainly
on the character of the soil through which it passes
it follows that a knowledge of the nature and

chemical composition of different soils is essential for the proper interpretation of **water analyses.**

As we shall see, the substances which may be found in a drinking water are derived from various sources. Before we can decide whether or not a water is fit for drinking purposes we must know not only the amount of each substance present, but also the source from which it has been derived.

In what follows we assume that our readers are acquainted with the methods in use for conducting water analyses.

ANALYSIS

By **chemical analysis** the amount of any substance present can readily be ascertained and by putting together all the factors of the analysis we can guess at the source of the water, but an opinion as to the suitability of a water for drinking purposes given from data obtained by chemical analysis alone is as unscientific as it is in many cases untrustworthy; moreover, if we know the nature of the soil from which a water has been obtained we know exactly what substances we ought to find in the water, the labour of an analysis is very greatly reduced and any pollution is detected with much less trouble.

The substances found in water may be classified as follows :—

A. **Organic**.

(1) Of animal origin.

(2) Of vegetable origin.

B. **Inorganic**.

(1) Substances dissolved from the soil and rocks by the solvent action of water ; the greater the amount of carbon dioxide in the water the greater is its solvent action and the wider the range of soluble substances.

(2) Salts due to the action of acids derived from the decomposition of organic matter on the bases in the rock.

Both the organic and inorganic substances may be present in solution or held in suspension.

ORGANIC MATTER AND ITS SIGNIFICANCE

Organic matter being very unstable rapidly undergoes decomposition and oxidation.

The first stage in the oxidation of organic matter is the production of *ammonia*. The carbon of the organic matter combines with the oxygen in the water to form carbon dioxide, while the nitrogen of the organic matter is left to combine with the hydrogen in the water to form ammonia.

The next stage is the formation of *nitrous acid*, which at once combines with those bases in the rock for which it has the greatest affinity, and *nitrites* are formed. They are extremely unstable and rapidly become converted into *nitrates*, which represent the last stage in the oxidation of organic matter.

It is of great importance to ascertain whether the organic matter present in water is of *animal* or *vegetable* origin.

Animal matter *per se* is possibly not more injurious than vegetable matter but it possesses a potentiality for doing harm which renders its presence undesirable. It shows that the way is open for access of specific poisons such as those of typhoid fever, dysentery and cholera ; and although absence of a large amount of animal organic matter does not absolutely negative the existence of specific poison in the water, since a very small amount of excreta from a case of enteric fever mixed with gallons of water used for drinking purposes is sufficient to poison a community, nevertheless pollution by a large amount of organic matter is in itself positive evidence of danger.

FREE OR SALINE AMMONIA AND ITS SIGNIFICANCE

Ammonia in water is either derived from easily decomposable substances, such as urea, or combined with carbonic and other acids.   Its presence may be due to the following very different causes :—

1. All waters however pure contain a small amount of free ammonia.

Rain, from which all sources of water supply are directly or indirectly derived, is natural distilled water, but just as the first distillates on distillation of a sample of water contain a small quantity of free ammonia, so pure rain-water contains a small amount ; moreover, in addition to this, rain takes up ammonia, which is present in the atmosphere as a result of combustion of fuel and animal exhalations.   The amount in the neighbourhood of towns

is very much greater than in the open country ;
in Paris, for example, the quantity of nitrogen
brought down as ammonia in rain-water is stated to
be six times as great as it is in the open country of
Elsass. It is also greater near the earth than at
some height above the surface.

The amount of free ammonia in rain-water, as
estimated by the first stage of Wanklyn's albuminoid
ammonia process, is generally below 0·01 parts per
million.

2. Urine after it leaves the body becomes ammo-
niacal. This is brought about by the conversion of urea

$$CO \left\langle \begin{matrix} NH_2 \\ NH_2 \end{matrix} \right. \text{into carbonate of ammonia } (NH_4)_2 CO_3.$$

Water containing urine yields therefore a large
amount of free ammonia. We may consider from
0·03 to 0·08 parts per million as suspiciously high.

3. Free ammonia may also be derived from the
decomposition of vegetable organic matter or other
easily decomposable substances in the soil. More-
over, on the death of organisms in water, ammonia,
carbon dioxide and water are given off and con-
sequently the amount of ammonia is increased.

NITRITES AND THEIR SIGNIFICANCE

We have already seen that the formation of **nitrites**
is a stage in the oxidation of organic matter, that
they are very unstable and rapidly become converted
into nitrates. Nitrites not being derived from the
soil their presence in water is an indication that
there has been recent pollution with organic matter.

NITRATES AND THEIR SIGNIFICANCE

Nitrates are the last stage in the oxidation of organic matter.

Their presence in water shows that organic matter has, at some period, contaminated the water, but that complete oxidation has since taken place. Pollution may have taken place a long time ago, or fairly recently. If nitrites are present as well as nitrates it indicates that all the organic matter has not been completely oxidised, that pollution is still going on or has been so recent that sufficient time has not elapsed for this purpose.

The organic matter whose former presence is indicated by the nitrates may have originally been derived :—

From polluted soil or defective drains and cesspools ;

From organic fossiliferous remains ; in deep chalk wells for example nitrates are always found in large quantity.

CHLORIDES AND THEIR SIGNIFICANCE

1. Rain-water at a distance from the sea-coast contains only a very small amount of **chlorides** (0·3 grains per gallon or less).

2. Near the sea, water contains chlorides in large quantities. This is due to the atmosphere being laden with " sea-salt " which is absorbed by the rain

and thence passes into the water supplies, and possibly also to sea-water percolating through the soil and directly contaminating the water supplies. Thus in Durham near the sea-coast the well-water has been found to be distinctly saline.

If "isochlors" are drawn, that is to say lines connecting wells of equal depth containing the same amount of chlorides, it is found that, *ceteris paribus*, the further they are situated from the sea the less chlorine do the wells contain.

The influence of high and low tides on the proportion of chlorides in a well near a tidal river was shown by De Chaumont who analysed samples of water taken from a well 83 feet deep situated 2,250 feet from the nearest point of the Hamble River in Hampshire ; the chlorides fluctuated according to the state of the tide, ranging from 2·45 grains per gallon at low water to 2·8 grains per gallon at high water.

3. Water may take up a large amount of chlorides in its passage through strata containing sodium chloride ; in triassic clays of Cheshire, Worcestershire and other places there are large deposits of rock salt, and wells may be sunk into rich springs of brine. With the deposits of rock salt (or sodium chloride) are often associated chlorides of magnesium and potassium, also very frequently gypsum.

4. Urine always, except in acute febrile diseases such as pneumonia, contains chlorides in large amount ; hence water contaminated with sewage will give high chlorides on analysis.

SULPHATES AND THEIR SIGNIFICANCE

1. Water may take up **sulphates** from the soil. Water, for example, which has percolated through dolomite contains a large amount of magnesium sulphate and some calcium sulphate.

Gypsum is directly soluble in water to the extent of one part in 500 of water ; this mineral occurs in very large quantities in the New Red Marl of England and in the Magnesian Limestone. It is also found as described below in certain clays.

2. Urine always contains sulphates.

PHOSPHATES AND THEIR SIGNIFICANCE

Although **phosphates** are rarely found in any considerable quantity in water, they are of importance as indicating organic pollution. Phosphates are, it is true, in some places found in considerable quantities in the ground ; for instance, the Greensand and Chalk Marl of Buckinghamshire, Bedfordshire and Cambridgeshire overlying the Gault contain numerous phosphatic nodules or concretions known as "Coprolites ;" these are also found in the Coralline Crag which overlies the London Clay ; they are much worked for manure and were formerly supposed to be the fossil excreta of certain vertebrates ; but they consist of material which is only slightly soluble in water, and it cannot be said that any soil will contribute a large proportion of phosphates unless it is contaminated with animal matter.

Thus the drainage water from cemeteries has been found to contain phosphates in considerable quantities.

HARDNESS AND ITS SIGNIFICANCE

Those dissolved saline constituents of the water which decompose soap are said to constitute **hardness** in water (iron and alumina have a similar effect). These salts are usually carbonates and sulphates of calcium and magnesium.

The fatty acids of the soap unite with the bases in the water to form insoluble oleates, stearates, palmates, &c., of calcium and magnesium, while the alkali of the soap unites with the acids of the bases in the water.

After this double decomposition, in other words when sufficient soap has been added to exhaust these hardening salts, the water lathers freely.

Hardness is distinguished as :—

A. **Temporary Hardness.** Due to calcium bi-carbonate, $CaH_2(CO_3)_2$, and magnesium bicarbonate, $MgH_2(CO_3)_2$. On boiling the water, carbonic acid is driven off and the bicarbonates are reduced to the insoluble carbonates of calcium and magnesium, the temporary hardness being thus got rid of. A little of the magnesium carbonate re-dissolves on cooling and contributes to the permanent hardness.

B. **Permanent Hardness.** Due to the presence of salts of calcium and magnesium (the sulphates, chlorides and nitrates) which are soluble in boiled

distilled water, that is to say in water from which all the carbonic acid has been driven off. No effect, therefore, is produced on the permanent hardness by boiling the water.

If the total hardness is below 6 grains per gallon the water may be considered soft ; if above this, hard.

Those rocks then which contain much lime and magnesia will make water hard, and the following are some of the rocks which yield hard waters :—

> Oolites.
> Chalk.
> Magnesian Limestone (Mountain Limestone).
> New Red Sandstone.
> Upper Greensand.
> Lias.

On the other hand those rocks which contain little or no lime or magnesia will yield soft waters ; such rocks, for example, as :—

> Igneous.   Bagshot Beds.
> Metamorphic.   Wealden.
> Millstone Grit.   Old Red Sandstone.
> Lower Greensand.   Cambrian.

WATER FROM THE PEAT

Water from the **peat**, as might be expected, contains a large amount of vegetable organic matter. The water "keeps" well, that is to say the organic matter is very stable and does not readily decompose.

(*Cf.* the remarks on p. 31.) For this reason peaty water was formerly much used for storage on board ship.

As a drinking water its yellow colour is rather against it (the dark colour of peat streams is familiar), but if the amount of vegetable organic matter is not excessive (over 0·2 parts per million albuminoid ammonia), it is a passable drinking water and its stability is a point greatly in its favour.

As regards the purely mineral constituents, an analysis of Manchester water derived from the peat of the Derbyshire moorlands gave :—

SiO_2	0·3	grains per gallon.
$CaCO_3$	1·7	do.
$MgSO_4$	1·7	do.
$NaCl$	0·9	do.

As is indicated by this analysis, water from the peat is soft and leaves only a small solid residue on incineration.

WATER FROM THE CLAY

Water from the **clay** contains a large quantity of hydrated sulphate of calcium (gypsum), and is therefore sometimes called "selenitic" water. Gypsum (or selenite) is not an essential component of clays, but is a secondary product resulting from the decomposition of iron pyrites which is present in most clays.

In moist air, iron pyrites is readily decomposed ; oxide of iron is formed, sulphur passes into sulphuric acid which attacks carbonate of lime derived from

shells in the clay, and the result is crystallised selenite.

These permanently hard waters are often called "brackish" waters, but they are not salt waters in the true sense of the word.

Water from the clay (owing to the impermeability) is stagnant surface water, very liable to be polluted and generally containing much suspended matter. The permanent hardness due to sulphate of magnesium as well as sulphate of calcium greatly exceeds the temporary hardness. The total solids may be as high as 200 grains per gallon.

Not only is water from the clay unfit for drinking purposes but there is a very small supply of it, few springs existing in clay soils.

On the other hand there are certain instances of good drinking water derived from clay. Thus at Woburn in Bedfordshire a layer of fuller's earth twelve feet in thickness enclosed in the Lower Greensand yields very pure water, and Mr. Cameron states that blocks of this earth are even placed in the wells of the neighbourhood which draw their water from other formations, in order to purify the water.

WATER FROM CALCAREOUS ROCKS

(*a*) **Water from the Chalk.**

Chalk being a uniformly porous rock acts as a filter. Organic matter present in the water is oxidised and innocuous mineral compounds are formed, so that water from deep wells in the chalk is organically very pure.

Water charged with carbonic acid, derived partly from the atmosphere but chiefly from the soil, dissolves the rock and huge reservoirs are formed in the chalk, the water in these being heavily charged with calcium carbonate.

The following indicates the hardness of water from the chalk :—

<div align="right">Grains per gallon.</div>

Total Solids   26
Hardness—
      (1) Total   19
      (2) Temporary   . . . .   14·8
      (3) Permanent   . . . .   4·5

The Kent Water Company's water derived from chalk wells yielded—

$CaCO_3$ . . . . .   20·3 grains per gallon.
$MgCO_3$ . . . .   1·5   do.
SO_3 . . . . . .   3·8   do.

(b) **Water from Magnesian Limestone (Dolomite).**

The water is organically very pure, but it is too permanently hard to be a wholesome drinking water.

The salts present are chiefly sulphate and carbonate of calcium and magnesium, and the total solids rarely exceed 20 grains per gallon.

Water from magnesian limestone differs from chalk water ·in containing a large amount of permanent hardness, whereas water from the chalk contains a large amount of temporary hardness. Sunderland obtains its water supply from magnesian limestone, but with this exception the magnesian limestones are not in this country a great water-bearing stratum.

(c) **Water from the Oolite**.

The water from oolitic limestone very much resembles water from the chalk as regards hardness, and is an excellent drinking water if derived from a fairly deep source ; it should however be remembered that in any rock which is frequently fissured water derived from shallow wells is liable to contamination, and this is true of many districts consisting of limestone belonging to the oolitic series.

WATER FROM THE SANDSTONES

As an abundant source of water supply **sandstones** rank superior to chalk, but the water derived from them, although it varies considerably, is generally impure.

The New Red Sandstone, for example, is a ferruginous rock and uniformly porous. As water passes through the rock some of the suspended matter is removed by filtration and organic matter to a great extent oxidised, but owing to the extreme porosity of the rock there is great liability to contamination of the water.

The water is moderately hard because the particles of quartz, which is the basis of the rock, are cemented together by carbonate, and sometimes sulphate of lime, together with oxide of iron ;—the permanent hardness is excessive and iron is present ; the chlorides are generally high because rock salt abounds ; sodium carbonate and sulphate are also present ; the total solids vary from 25 to 90 grains per gallon.

The following analysis, made by Frankland, of

water from a deep well in the town of Nottingham shows some of the chief characteristics of water from the New Red Sandstone :—

		Grains per gallon.
Total Solids	. . . .	43·9
Chlorine	. . . .	3·9
Hardness (total)	. . . .	13·8
(1) Temporary	. . . . . .	6·7
(2) Permanent	. . . . . .	7·1

WATER FROM METAMORPHIC AND IGNEOUS ROCKS

Water from the **metamorphic rocks** is practically rain water. The rock being extremely hard and insoluble acts as a large impervious basin, and since rain water (away from the neighbourhood of large towns) is very pure, water from the metamorphic rocks is also of great purity. The total solids are very low, from two to four grains per gallon, and consist chiefly of sodium carbonate and chloride together with a little lime and magnesia.

WATER SUPPLIES

Of primary importance from the hygienic point of view is some knowledge, not only of the superficial soil, but of the *underground geology* of any district ; this is of course mainly derived from wells, mines and deep borings, but much is learnt from the consideration of the sequence described on p. 23, combined with the study of the " dip " or direction in which the successive strata slope beneath the surface. Impervious strata may retain the percolating waters to a considerable extent and raise the underground

water-level, thus affecting climate as well as water supply. Again, as regards the nature of the water to be obtained from wells, a subterranean clay basin will afford a favourable condition for water to be tapped by borings ; but the character of this water— its hardness or softness—will depend upon the nature of the calcareous or siliceous formations which overlie the clay.

Although the underground geology of England and Wales is by no means fully understood, certain general facts are of extreme importance. Thus, in the Cretaceous group, the Greensand underlies the chalk and not only receives but filters the water which has traversed the superjacent stratum ; moreover, the Greensand is itself succeeded by the Weald Clay which prevents the escape of this water ; accordingly the Greensand is a receptacle for good (though hard) drinking water throughout the cretaceous and the newer strata. Some of the water of London and other places situated on the London Clay is derived from wells sunk through the underground chalk into the Greensand ; the New River Company derives a supply of chalk water from springs in Hertfordshire, and the Kent Water Company draws from chalk wells in several places.

In the Thames basin the Lias retains the water which percolates through the Lower Oolite and gives rise to the principal springs which feed that river.

The best well water supplied by water companies in various parts of England is obtained from the chalk, the Oolites, the New Red Sandstone and the

Lower Greensand ; the Cornbrash, a shelly limestone underlying the Coral Rag and overlying the Forest Marble, is also water-bearing. Thus, for example, water is derived from :—

The *New Red Sandstone* at Birkenhead, Coventry, Leamington, Southport, Nottingham and Liverpool ;

Lower Oolite at Bedford, Scarborough and Bath ;

Chalk at Cambridge, Canterbury, Deal and Bury St. Edmunds ;

Upper Lias Clays and Sands at Northampton ;

Magnesian Limestone at Sunderland ;

Millstone Grit and Coal Measures at Sheffield ;

Calcareous portion of the Coal Measures at Stockton and Middlesborough ;

Mountain Limestone at Newcastle ;

Metamorphic Rocks at Glasgow, where the water is largely supplied from Loch Katrine which lies upon gneissic rocks.

DISEASES ASSOCIATED WITH DRINKING WATER

Having seen the way in which water may take up mineral and other matter from the soil we pass on to consider the ill-effects that such substances may exert when introduced into the body.

The greatest danger to health from drinking water lies in the fact that the **germs** of some specific disease, such as *enteric fever*, may be taken into the human alimentary canal, and, as we have pointed out, one of the best methods at present available of measuring this potentiality for doing harm (since bacteriological

investigation of water is not as yet very satisfactory) is by estimating the amount of animal organic matter present. This, however, is quite outside the scope of the present book, and we shall discuss only the effects of certain vegetable and mineral constituents of water. Before doing so, however, it may be as well for the sake of non-professional readers to state two elementary facts :—in the first place, only a certain proportion of individuals who may happen to drink water contaminated with the specific poison of a disease, such as enteric fever,·will acquire that disease ; and in the second place, there is a period (technically known as the *incubation period*) which varies in different diseases, during which time the poison is circulating in the system without producing any symptoms, so that there is an interval between the contraction of the disease and the development of symptoms.

Vegetable Matter. Undoubtedly an excess of vegetable matter in water—some peaty waters for example—may cause *diarrhœa*, and outbreaks of this malady have been traced to such a cause. Again, marsh water is popularly, and with reason, believed to be capable of producing *malaria*. This is supposed to be due to the large amount of vegetable matter present, but it is possible, assuming the bacterial theory of malaria, that such water may contain the specific bacilli or their spores, and that therein lies the real explanation.

We quote the following instance from a report on intermittent fever amongst troops quartered at Tilbury Fort, mentioned by Deputy Surgeon-General W.

J. Fyffe, M.D.   " Tilbury Fort in the Essex Marshes is supplied with rain water which is collected on the roofs of various buildings, and, before entering two large cemented tanks placed underground, passes through charcoal filters.   A body of troops arrived at the fort on the 18th of December 1873, and remained until July 1874.   During this period the tanks were under repair and empty, and the troops were supplied with spring water for drinking and cooking purposes from the railway station.   The tank water was not used at all.   Only one case of ague occurred in the garrison in this period of seven months.

" After the tanks had been repaired and came again into use, a fresh body of troops came to the garrison to relieve those already alluded to, and in the course of six months 12 per cent. of their number were attacked with intermittent fever.   The troops used during this time *not* the spring water from the railway station, but the rain water from the underground tanks.

" The fair assumption therefore was, that these rain-tanks being sunk in marshy ground, the malarial poison had percolated with the subsoil water through the walls of the tanks and contaminated the water, and that the malarial poison had thus gained access to the men.   This assumption was strengthened by the fact that there were no other cases among the civil population in the neighbourhood at the time."

Mineral Matter.   With regard to the inorganic constituents of water, certain diseases, notably bron-

chocele and calculus, have since a very remote period been ascribed to their agency.

Bronchocele (goître) has been considered to be due to an excess of magnesian salts and to excessive hardness &c., yet it abounds in some districts where the water contains a small amount of magnesian salts, and in others with a soft water supply.

The well-known "Derbyshire neck" is often quoted as an example of the magnesian limestone theory, but cases of bronchocele are rare in some places where the same conditions exist. There certainly is evidence that water may, under certain circumstances, produce bronchocele, but the exact condition of the water which causes it is unknown.

We know that bronchocele is sometimes due to general conditions : it may, for instance, be dependent on anæmia or associated with exopthalmos ; a temporary enlargement of the thyroid gland is not uncommon during pregnancy. And as our knowledge extends and we become better acquainted with the exact functions of the thyroid gland, it is probable that it is to general conditions, such as those mentioned above, that we shall look for the causation of the majority of cases of bronchocele.

So too with regard to *calculus*, it is absurd to suppose that all varieties of calculus, such as uric acid, oxalate of lime &c., have one common cause, viz. a hard drinking water. There is, in fact, no proof at all that any form of calculus is ever caused in this way.

It is perfectly true that calculus is much more com-

H

mon in some districts than in others—on the East Coast
of England where the water supply is usually harder
than on the West—but it is very rare in certain parts
of Central England where the water is equally hard.
Further, it is more common in some races than in
others, being, for example, almost unknown among the
South African negroes ; and is more frequent amongst
children of the lower than the upper classes ; in short,
it seems much more probable that an explanation is
to be found in diet, constitution, race and causes of
this class, which have not been at all fully worked out
at present.

It is certainly a fact that hard waters, especially if
permanently hard, are injurious in some people to
the *digestive processes*.   As an example we give the
following case :—an ardent teetotaler, in robust health,
who had been in the habit for some years of drinking
daily a large quantity of very soft water, moved to a
district where the water supply was permanently hard ;
dyspeptic symptoms at once showed themselves and,
in spite of medicinal treatment, became chronic : this
gentleman was then induced to drink only distilled
water ; the dyspepsia vanished and there was no
recurrence.

The injurious effect of permanently hard water on
the *skin* is well seen in animals, such as dogs and
horses, and grooms have a strong prejudice against
the use of such water for animals under their care.

Lastly, large quantities of sulphates of magnesium
and calcium in a drinking water may produce
diarrhœa.

We ought perhaps to mention that a hard water is popularly supposed to cause those gouty deposits which are known as " chalk stones."   These really consist chiefly of urate of sodium together with a small amount of urate and chloride of calcium ; they are local manifestations of gout, and are not in any way caused by hard water.

CHAPTER V

THE SOIL IN ITS RELATION TO AIR

" As the aire is, so are the inhabitants, dull, heavy, witty, subtle
neat, cleanly, clownish, sick, and sound."
—BURTON.

THE ATMOSPHERE

THE air is commonly regarded only as an atmospheric envelope surrounding the solid earth, little account being taken of the air which may penetrate the ground and extend below the surface ; and yet this, as we shall see, plays an important part in the economy of Nature and must not be neglected any more than the ground water in considering the properties of the soil.

In fact the earth is to be regarded as a porous globe, not only immersed in the atmosphere, but to a certain unknown depth soaked with air which permeates the soil and fills all the interstices when they are not occupied by the ground water.

We have, therefore, at the outset, to distinguish between atmospheric and ground air.

Atmospheric air is a *mixture* and not a chemical compound ; its average composition by volume is as follows :

Oxygen . . . . 20·96 per cent.
Nitrogen . . . . 79·00   „
Carbonic Acid . . . . . . 0·04   „

It also contains a variable quantity of water vapour and a very small proportion of ammonia.

The nitrogen contained in the air is practically an inert gas, which serves to dilute the oxygen and does not play any important part in the chemical changes continually taking place in and above the soil ; the oxygen is withdrawn from the air and enters into combination with other substances, both during the oxidation of minerals and in almost all organic processes ; it is constantly restored to the atmosphere by the action of plant life.

The amount of water vapour contained in the air depends mainly upon the amount of water, such as seas, rivers or lakes in its proximity, and upon the temperature ; thus the large rainfall on the west coasts of Great Britain and Ireland indicates how moisture-laden are the prevalent westerly winds which reach those coasts after sweeping the surface of the Atlantic Ocean : again the effect of change of temperature is shown by the excessive rainfall in the more mountainous coast districts as compared with the plains ; for when moist air is driven up into more elevated and colder regions it is no longer able to retain the moisture which it holds near the surface of the ground where the temperature is higher.   The

weight of water capable of being taken up by one
cubic metre of air at 10° C. (50° F.) is 9·4 grams; at
freezing point about half this amount.

Carbonic acid is supplied to the air by most
of those processes which remove oxygen, such as
the respiration of animals, combustion and organic
decomposition. It is removed from the air by plant
life, by solution in rain water and by some inorganic
decomposition; thus a cubic metre of felspar in
decomposing to clay absorbs no less than 200
kilograms of carbonic acid.

GROUND AIR

Pettenkofer demonstrated the presence of air in
gravel soil by enclosing a bird between two layers
of gravel in a large glass cylinder; the bird obtained
the necessary supply of oxygen from the gravel and
at the end of ten hours was perfectly well.

And it has been shown that all soils contain **ground
air,** loose porous soils as much as 50 p. c. Even
frozen ground is not impermeable to air, and it is only
the most compact rocks that may for all practical
purposes be considered as free from it.

The processes which take place in the soil are such
as may be expected to increase the percentage of
carbonic acid in the ground air; on passing into the
soil the oxygen of the atmosphere combines with
carbon derived from the animal and vegetable matter
of the humus, and carbonic acid is produced; some

of it appears to be due to the direct action of putre-
factive organisms.

As a result of various putrefactive and other changes
the percentage of carbonic acid is always found to be
greater in ground air than in the atmosphere, and to
increase with the depth.   At Budapest, Fodor found

At a depth of 1 metre   0·9 to 1·0 vols. of CO_2 per cent.
,,   ,,   4 metres 2·6 to 5·4   ,,   ,,   ,,

At Dresden, Flech found

At 2 metres 2·99 per cent.
,, 6 ,,   7·96   ,,

The proportion of carbonic acid increases with the
temperature and the moisture of the soil; it was
found at Munich that the proportion also varies with
the season, the maximum being attained in July and
the minimum in January.

It has also been found that, generally speaking,
loose crumbling soils contain less carbonic acid than
compact and powdery soils, which are not so easily
penetrated by the air; and also that there is four
times as much carbonic acid in the ground air of
fallow land as in that of cultivated districts.   This
is not surprising, for where free circulation of the
ground air is possible the proportion of carbonic acid
is never so great as in those soils where the air is
more closely confined and less frequently replaced.

The amount of *oxygen*, on the contrary, decreases
with the depth since this gas is withdrawn by the
oxidation of the organic matter.

Oxidation takes place to a much greater extent at

the surface of the ground, and in the superficial
layers of the soil than at a greater depth, where there
is little or no free oxygen.

Fodor found

At 1 metre   18·7 to 21 per cent.
 „ 4 metres 17·9 to 18·5   „

In freshly manured moist soil Boussingault found
the percentage of carbonic acid to be as much as 9·5,
and that of oxygen only 10.

The amount of *nitrogen* in the ground air is almost
constant, and the same as in the atmosphere, namely
about 79 per cent.

Besides carbonic acid, oxygen, nitrogen and
moisture, the ground air also contains other products
of fermentation and decomposition, such as ammonia,
and occasionally ammonium sulphide, hydrogen
sulphide and marsh gas.

Thus accumulations of hydrogen sulphide and car-
bonic acid have been found during the sinking of
wells at certain levels even in the chalk ; the former
possibly resulting from the decomposition of iron
pyrites. During the construction of the Thames
Tunnel both hydrogen sulphide and marsh gas issued
with violence from the London clay.

Another property of the soil which makes the
composition of ground air different from that of the
atmosphere is its *varying absorptive power* for differ-
ent gases ; thus different soils absorb nitrogen and
oxygen to a different extent, and no soil will absorb
them in exactly the same relative proportion in
which they are mixed in the atmosphere ; nitrogen is

generally more easily absorbed than oxygen, and this may tend to diminish the excess of nitrogen over oxygen, which would otherwise result from the processes in the soil.

MOVEMENTS OF GROUND AIR

The air in the soil, like the ground water, is not stagnant, but is in constant movement ; to demonstrate this Pettenkofer filled a high glass cylinder with gravel down to the bottom of which he thrust a smaller glass tube open at both ends—the lower end embedded in the gravel, the upper end connected with a manometer.   On blowing gently on the surface of the gravel he found that the liquid in the manometer moved, thus proving that in porous soils the ground air must be set constantly in motion by such agencies as the **wind blowing against the surface of the ground.**

This continual movement of the ground air is of very great importance from a sanitary point of view. As we have seen, it contains always a large amount of carbonic acid, and occasionally gases resulting from organic decomposition, as ammonium sulphide, or even sewer gas ; moreover we have seen in a previous chapter, that certain pathogenic micro-organisms exist in the soil, so that their spores may be caught up and carried by the ground-air.

As to the agencies by means of which the ground-air is kept constantly in motion, besides the wind blowing against the surface of the ground, there are

many other forces constantly in action, such for instance as :—

Changes in barometric pressure. With a low pressure, ground-air will escape from the deeper layers of the soil.

Again, especially after a long period of drought when the barometer has been high and consequently the pressure of the atmosphere has prevented any great rise of soil air, **heavy rain** will force the ground-air to a deeper level, but it will also force it out of the ground at those places which still remain dry—and in this way ground-air may escape into houses if the basement floors have not been properly cemented.

In a previous chapter we pointed out that epidemic pneumonia was possibly caused by the bacillus pneumoniæ, and that the epidemics of pneumonia at Scotter were associated with a polluted condition of the soil.

Some of the outbreaks that occurred, followed on periods of prolonged drought when heavy rains forced air out of the loose and porous soil, and it seems possible that this air contained the spores of the specific bacillus which found a suitable nidus in the grossly polluted soil.

We have already alluded to the importance which Pettenkofer attaches to **variations in level of ground-water**, chiefly because this facilitates the action of certain obvious processes in the soil; but also because it forces out air contaminated with specific poisons, since fluctuation in the ground-

water will bring about a corresponding movement in the ground air.

Lastly, and probably the most important of all, are the **changes of temperature** which constantly take place.

Atmospheric air and the ground-air are seldom at the same temperature. The curves for the ground temperature at different depths show little fluctuation —they are very uniform when compared with those of the atmosphere. In spring and summer, as is explained below, the soil is cooler than the atmosphere, hence the ground air will tend to pass into the deeper layers of the soil. In autumn and winter the reverse takes place.

Besides the seasonal differences of temperature there is a daily range for soil and for air the lines of which hardly ever correspond for even a short time— we shall allude to this again when dealing with the action of the soil upon atmospheric air.

As an illustration of the effect that differences of temperature have upon ground air, we may mention the aspirating power of houses artificially warmed and unprovided with a proper concrete basement. Local gas emanations have been found in such houses, although no gas has been laid on to the houses themselves, and in one case quoted by Pettenkofer, coal-gas passed from a pipe twenty feet under the ground through foundations, cellars, vaults and finally through floors into the rooms of a house.

Foul air from a defective drain may in the same way contaminate the air of houses, unless a thick

layer of concrete is placed between the ground and basement of the house.

Some very interesting facts bearing on this, and confirming to some extent Pettenkofer's idea that typhoid fever may be communicated to man by means of contaminated air, have recently been brought forward by Sir Charles A. Cameron.   In Dublin there is a persistent occurrence of typhoid fever, which cannot be accounted for either by polluted water, milk or food ; in fact an improvement in the water supply was not followed by any decrease in the amount of typhoid fever. Sir C. Cameron attributes this prevalence of typhoid fever in Dublin to the practice which has been in use for centuries of storing excreta in pits, so that the soil is thoroughly impregnated with the specific organisms of the disease, which are carried into the atmosphere by the currents of ground-air.   Moreover, as some additional proof, the ratio of cases to population living in Dublin on gravel soil for ten years (1881–1891) was 1 in 94—the ratio for those living on clay 1 in 145 ; and this is what we should expect, since the movements of the ground-air are much greater in loose porous than in stiff clay soils.

Another very interesting point is this :—recently the streets of Dublin have been paved with stone, and at the same time there has been an increase of typhoid fever ; this may be accounted for by the fact that (in the words of Sir C. Cameron) "the underground air cannot now diffuse into the atmosphere over the road-ways, and therefore may be drawn in larger quantities

into the houses, the basement floors of which are rarely concreted."

Somewhat similarly it appears from recent reports that cases of poisoning by carbonic acid (CO_2) in ground-air, and by carbon monoxide (CO) due to the escape of coal-gas from underground pipes, are most frequent during prolonged frost when the ground is more impervious than usual, so that gases are prevented from escaping through the frozen surface of the ground and enter houses unprotected by a proper basement.

THE INFLUENCE OF THE SOIL ON CLIMATE

Having dealt at some length with ground-air we have now to consider briefly the influence which the soil exercises upon the atmosphere. In the first place some soils are more easily heated than others, or in other words have a less **specific heat.** The specific heat of a substance may be defined as the quantity of heat which is required to raise unit mass of the substance through 1°C.; the unit of heat adopted being the quantity of heat required to raise one kilogram of water through 1°C.

The specific heat of water then being unity, it will be seen from the following table that the minerals of which rocks and soils are composed have a far lower specific heat than water.

SPECIFIC HEAT OF MINERALS.

Quartz	0·188
Felspar	0·190
Calcite	0·204
Mica	0·205
Limonite	0·221

SPECIFIC HEAT OF ROCKS.

Granite	0·192
Slate	0·207
Basalt	0·270
Limestone (compact)	0·245
Clay	0·160
Humus	0·600
Sand	0·275
Loam	0·259
Marl	0·284
Granite (weathered)	0·301

This table indicates that humus is warmed with greater difficulty than any other soil, and that all soils are far more easily warmed than water.

Radiation and Absorption. Any substance which is a good absorber of heat is also a good radiator, and a bad absorber is a bad radiator; hence water both becomes heated and also parts with its heat far more slowly than does the ground. For this reason a soil which is impregnated with moisture, such as a damp clay, has a higher specific heat than a dry porous soil such as sand, and will become less heated by the rays of the sun or is said to be a "cold soil."

Now the temperature of the ground is important not only in its direct bearing, but also because it largely influences the temperature of the atmosphere. It is commonly stated that dry air is diathermanous or allows the free passage of radiant heat, but that moist air is adiathermanous, or absorbs a considerable proportion of the heat radiated by the sun; that a perfectly dry atmosphere is never met with in nature, and consequently that the air is warmed both by the heat of the sun's rays, and that radiated from the

earth. The experimental evidence on this point is somewhat contradictory, but tends to show that water vapour absorbs radiant heat only to a very limited extent, and we may conclude that the temperature of the air is mainly determined by that of the ground. The lower layers of the atmosphere are first warmed by contact with the earth, and then expanding rise and so increase the general temperature by convection. Another noteworthy source of atmospheric warmth is the condensation of the water vapour which it contains.

The stratum of air nearest to the earth is found to be the hottest, and a fall of 1°C. is observed in the atmospheric temperature for every 550 feet of elevation above the earth, until above the level of perpetual snow the atmosphere is always below freezing point.

Conductibility of Heat. All soils and the minerals of which they consist are bad conductors. Hence if two neighbouring portions of the ground are at different temperatures they remain so for a long time, and do not rapidly attain the same temperatures as would be the case with a conductor like a metal.

Dry clay has been found to be a better conductor than dry chalk ; the presence of water increases the conductibility, while the presence of air in the interstices of the soil reduces its conducting power ; humus is a particularly bad conductor, as are also soils containing much lime or magnesia.

The Colour of the Soil. Dark materials always absorb more of the radiant heat than light-coloured materials ; it has been found, for instance, that with

the same exposure to the sun's rays and with the temperature of the air at 25° C. (77° F.) white sand attained a temperature of 43·2° C. (110·7° F.), while sand with a black surface rose to 50·9° C. (123·8° F.) For this reason humus will tend to become more heated by the sun's rays than other soils. It is stated that the colour of a dark soil alone is sufficient to hasten the ripening of fruits &c. by one or two weeks.

Other sources from which the soil obtains heat are the **chemical actions** constantly taking place within it which are attended by a rise of temperature ; and the condensation of gases by which also heat is liberated.

From all the above considerations it results that the **temperature of the ground** is not the same as that of the atmosphere, but is generally higher ; that the temperature of the ground is different in different places ; and that these variations depend almost entirely upon the nature of the soil.

Owing to the slow conduction of the soil the changes of the surface temperature are not felt until long after they take place at the surface ; this is true both of the changes between day and night, and also of those variations which are due to the succession of the seasons.

It may be laid down as a general rule that the surface soil is by day warmer, and by night colder than the air ; that the subsoil reaches its maximum

and minimum temperature later than the surface soil,
so that the subsoil is in summer colder, but in winter
warmer than the surface soil ; and that at a depth
exceeding 17 metres these annual variations are not
felt, but the rock remains at the same temperature
at all seasons of the year. Below this the temperature
of ground increases regularly by about 1° C. for every
100 feet owing to the internal heat of the earth.

The temperature of the soil is reduced by radiation
and by the evaporation of water which is always
accompanied by an absorption of heat. Direct
experiments have been made on the radiation of
soils and have shown that to fall from 62·5° C.
(144·5° F.) to 19° C. (66° F.) the following times were
required by equal quantities of various soils :—

Peat	120 minutes.
Humus	127 ,,
Limestone	158 ,,
Clay	161 ,,
Loam	166 ,,
Fine sand	175 ,,
Coarse sand	192 ,,

Although at first sight it may not appear that the
temperature of the ground and the atmosphere has
any very important bearing upon health, yet when we
reflect that the difference of temperature gives rise to
air currents both in the atmosphere and in the ground-
air, it is clear that many of the conditions which are
implied by the word **climate** are determined by the
nature of the soil and of the rocks in its immediate
proximity, whether at the surface of the earth, or
those beneath it. In this connection the *relative*

temperature of the air and soil is of the greatest im-
portance ; for instance the prevalence of mists and
fogs is dependent upon these conditions.

The other factors which determine the character of
a climate such as aspect, prevalent winds, vegetation,
&c. are of course of equal, or even greater importance,
but lie beyond the scope of the present volume.

CHAPTER VI

GEOLOGICAL DISTRIBUTION OF DISEASE

" He that builds a fair house upon an ill seat committeth
    himself to prison."
                              —BACON.

COMPARISON OF SOILS

IN the preceding chapters we have seen how a
knowledge of the nature and properties of the soil is
necessary for hygienic purposes, especially in three
respects :

(1) The action of micro-organisms in the humus.

(2) The presence and nature of the water in the
soil.

(3) The influence of the soil on air, both atmospheric
and ground-air.

In estimating the relative advantages and disadvan-
tages of any particular soil, all these considerations
must be taken into account. An attempt to compare
in this way all the soils enumerated in the first
chapter would far exceed the limits of the present
volume ; we shall therefore only indicate briefly the

relative advantages and disadvantages of two soils of widely different characters, namely normal clay and sand, and leave the reader to apply the same method in criticising the soil of any particular locality. It must, however, be always remembered that the normal characteristics of any soil may be entirely transformed by the hand of man through drainage, tillage, cultivation, water supply, &c., and in any inhabited district these artificial conditions are of no less importance than the natural properties of the ground ; but the consideration of such matters belongs rather to sanitary engineering, and our present object is merely to direct attention to the properties of the soil itself.

CLAY SOILS

These when pure consist mainly of silicate of aluminium, but invariably contain also hydrated oxide of iron and some silica (quartz).

Impure clays contain a considerable proportion of calcareous or siliceous matter ; marls and other calcareous clays may be regarded as possessing much the same characters as those here enumerated for true clays, but the most siliceous clays, such as sandy loams, partake more of the nature of sands.

The most important feature of clay is its impermeability ; this, combined with a considerable absorptive power, renders it capable of holding much moisture and generally speaking a clay is essentially a damp soil ; neither is this character easily altered by direct drainage of the clay.

As a surface soil, clay occurs filling basins and hollows of the ground into which it has been washed by the action of water ; it has not sufficient coherence to rest upon sloping ground, and so presents in general a more or less flat surface and tends to retain the stagnant water which may accumulate upon the surface.

As subsoils, clays are often interstratified with loams and sands and in that case retain the water which percolates through the more porous rocks overlying the clay.

Before the introduction of deep borings the water in a clay district has always been derived mainly from shallow wells, and these of course are only found where there is some more porous soil overlying the clay. It is instructive to note that in the early history of London, houses were first built only at those points where patches of sand or gravel yield surface water, and did not spread over the exposed London clay till a later period when use could be made of deep wells or of the Thames water. We can even now trace the localities of these wells by the names which still cling to certain parts of the town, such as Clerkenwell, Holywell, Ladywell, Shadwell and Camberwell.

In the second place a clay soil is not only damp but cold, both because its specific heat is low and also because constant evaporation is going on at the surface of the ground ; and, as is well known, all evaporation is accompanied by a reduction of temperature.

The importance of these properties of a clay soil as regards phthisis, rheumatism and similar diseases has

been already pointed out, but it must be remembered that *such disadvantages may be largely reduced by an efficient system of subsoil drainage.*

As the subsoil water is withdrawn and its level is lowered, more air is admitted into the ground and the temperature is raised, while at the same time dampness is reduced.

It has been found that in spring the temperature of well-drained land at a depth of eighteen inches below the surface is two degrees higher than that of undrained land at the same depth ; and the observations of Professor Schubler at Tübingen showed that in that town the effect of subsoil drainage was to raise the mean annual temperature of the ground, at a depth of four feet, by six degrees.

A third disadvantage of clay soils is that the quality of the water derived from them is not good ; water from the clay being, as we have seen in a previous chapter, "selenitic" and very liable to pollution.

As regards its relation to the air, a clay soil is naturally poor in ground air, which is moreover not free to circulate to the same extent as in porous soils, and consequently becomes vitiated. The atmosphere above a clay soil tends to become damp and cold like the ground with which it is in contact.

Against the above considerations we have to set the advantages of clay soils. In the first place, owing to the impermeability of the soil, there is less chance of contamination of the drinking water by defective cesspits if such a method of drainage is adopted, and

further complete saturation of the soil is probably unfavourable to the life of certain organisms.

Again, a clay soil on account of the high specific heat and the bad conduction and radiation of its material, as well as of the water which it contains, is not liable to sudden changes of temperature ; and further it may be true of any soil which does not readily crumble and yield dust that pathogenic micro-organisms are less likely to become air-borne than when they find their habitat in dusty soils ; in this connection we may remind ourselves of the possible action of dust in transmitting phthisis in ill-ventilated factories &c.

It must not be forgotten that the character of the soil in any district depends largely upon the elevation, slope and configuration of the country. Thus the London clay, though impervious, is higher than the surrounding country and moreover it is partially covered with gravel, so that surface drainage takes place with comparative ease. The Weald clay of Kent, on the other hand, lies low, is flat, is not covered with gravel and is surrounded by hills ; all these conditions are adverse to drainage, and in consequence the Weald clay is more damp than the London clay. (See the map on p. 26.)

SANDY SOILS

Sands, as we have seen above, are mainly composed of grains of quartz, a hard, unalterable and nearly insoluble mineral, having a low specific heat.

All sands, however, are by no means alike, their character being largely determined by the cement which binds together the grains ; in a loose sea-sand there is little or no cement and the grains are loose, but in sandstones and terrestrial sands there is always some sort of cementing material, either calcareous, ferruginous or siliceous.

When the interstices between the grains are filled by clayey material, the soil partakes more of the nature of a clay or loam.

The cement may be *calcareous*, consisting of the carbonate of lime derived by the action of rain-water from sea-shells or from the infiltration of other calcareous solutions ; in this case the sand is sufficiently porous to be easily permeable by water and air ; it will therefore be a light soil capable of filtering the percolating water from mechanical impurities ; and will be a warm soil both on account of the low specific heat of quartz and carbonate of lime (calcite), and also because it contains air. On the other hand the percolating water will be hard.

(2) The cement may be *ferruginous*, consisting of hydrated oxide of iron deposited by percolating solutions ; in this case also the sand is a light porous soil, but is always coloured yellow or brown or even red by the oxide of iron ; this will be an additional reason for the warmth of the soil.

(3) The cement may be *siliceous*, consisting of secondary silica surrounding the sand-grains ; in this case the sand is more compact and less permeable than in the two preceding varieties ; for this reason

also it is less porous and contains less air, and in its most compact form constitutes a hard sandstone or quartzite.

(4) Sometimes the cement is *felspathic* as in the millstone grit. In this case also its characters will be allied to those of a clay soil.

The following may be enumerated as the disadvantages of a typical sandy soil :—

Owing to its permeability it will be readily liable to pollution from such causes as the leakage from defective cesspools ; the rise and fall of the ground water in a sandy soil may be considerably in excess of that in other soils, and it is not improbable that such oscillations of level have a prejudicial effect on health.

Again, the conditions which prevail in a sandy district are precisely those which, as we have already seen, are favourable to the life of certain microorganisms, namely the presence of moisture, warmth and a certain amount of organic matter.

Further, the water supply derived from sand is in some places very impure on account of the large amount of organic matter which may penetrate a loose porous soil ; and lastly, when a sandy deposit overlies an impermeable subsoil, the water of the district is often derived from shallow wells sunk in the sand, and these are naturally very undesirable sources of drinking water.

On the other hand the advantages of a sandy soil are those which result from its loose porous nature and permeability ; it is both warm and dry.

Under sandy soils we include, of course, gravels which consist of loose pebbles ; when compacted together by any cementing material (generally clay) they pass into conglomerates, which also possess to a large extent the characteristics of a sandy soil.

CALCAREOUS SOILS

We have seen in dealing with sandy soils as a whole that some difficulty is introduced, because the cementing material which binds together the particles of quartz may be of such a nature that the sandstone will have all the characters of an impervious soil such as clay, and from a hygienic point of view has to be classified with clays.

In the same way it is impossible to consider calcareous soils as one group because they differ very widely in their nature.

Limestones consist mainly of carbonate of lime, but generally contain also oxide or carbonate of iron. Many limestones are very siliceous ; others are argillaceous and gradually pass into marls ; in fact the characters of limestones are determined very largely by the impurities which they contain.

Under calcareous soils are included not only compact limestones, but chalk, oolite and chalk marl. Many of these formations attain very great thicknesses, so that the surface conditions are fairly independent of the nature of the subsoil.

From all the above considerations it will now be clear that in estimating the qualities of the soil in any

given district, we have to know the nature and pro-
perties of the minerals of which it is composed, and
that it is not sufficient to dispose of it with a meagre
description as a clay, sand or limestone.

It will also be obvious from the foregoing pages that
the same diseases will not necessarily be prevalent in
two given places where the soil is of the same nature ;
for instance, one village situated on clay may have an
efficient drainage system with a well-drained subsoil
and a pure water supply from a distance ; another
village on soil of the same nature may have no sub-
soil drainage, water supply from surface pools and
drainage into cesspits. We should not, under these
circumstances, expect a prevalence of the same dis-
eases in the two villages—indeed we might reasonably
expect that the inhabitants of the former village
would enjoy better health than those of the latter.

DISEASE MAPS

One of the most able writers on this subject is Mr.
Haviland, M.R.C.S. In a recent edition of his book
on the Geographical Distribution of Disease in Great
Britain, he discusses three diseases, viz : cancer,
phthisis and heart disease. One cannot but admire
the indefatigable energy with which Mr. Haviland
has laboured to interpret the mass of statistics bearing
on this subject and the successful manner in which
he has presented them in a graphic form.

With regard to the *method* in which these and
other maps of the kind are drawn up, the statistics of

the Registrar-General's office are made use of, England and Wales being for registration purposes divided into 11 registration divisions, 44 registration counties, and 623 registration districts (1851-1860). The process is thus described by Mr. Haviland :—

"In the first place we see what proportion the annual number of deaths from a cause of death bears to the population in each of the eleven *divisions ;* we colour blue or red those divisions which are above or below the average of the county and then study the gross distribution carefully. Our next process is to colour the *counties* in the same way and observe what counties dominate that of the divisions ; our third process is to discover how the proportional mortality of each county is influenced by the mortality in the *districts*."

We give here, by kind permission of Mr. Haviland, a reduced uncoloured copy of his *cancer* map at "all ages" for the counties of England and Wales. The darker shading represents the blue colour in Mr. Haviland's map ; the 11 divisions and the 44 counties are indicated by thick and thin dotted lines respectively.

We may say at once that we consider Mr. Haviland's data *insufficient* and his conclusions erroneous.

A similar method applied to the statistics of any other cause of death, such as homicide, would give a variously coloured map which might without difficulty be strained to indicate the predominating influence of some soil, as successfully as in the cancer map.
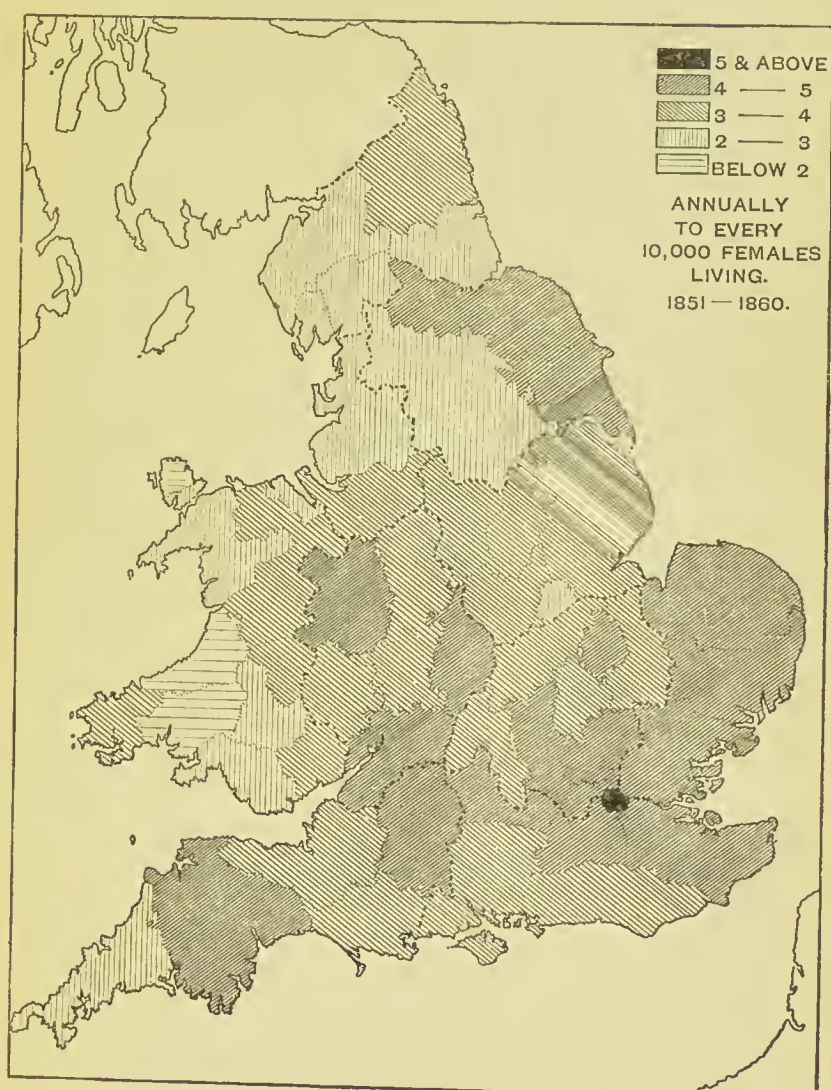
Walker & Boutall sc.

Cancer Map at all ages for England and Wales after Haviland.

The most striking feature which at once catches the eye is that the highest mortality occurs in the neighbourhood of London. Now we do not for a moment mean to suggest that this may be *entirely* explained by the fact that a very large number of patients flock to the metropolis for operative treatment—because districts round London have also a high cancer rate— but we would suggest that it is a factor of great importance, which must not be ignored in this and other parts of the country.

Further, the number of deaths from this disease in thinly populated districts must be so small that deductions from them can scarcely be trustworthy ; to ensure accuracy a very large number of observations must be employed. A difference of one death per 10,000 in two given counties is too small to be ascribed with certainty to any one cause.

Again, the diagnosis of cancerous diseases is very much more accurate at the present time than formerly ; and hence the returns for different periods are not equally trustworthy. There is not the slightest guarantee that a cancer map drawn up for one decennial period would coincide with that for another, even where there is no variation in the geological conditions.

With regard to the *conclusions* which Mr. Haviland draws from his cancer maps—he asserts that there is " an infrequency in places characterized by elevated sites and limestone formations or even by sites subject to floods, but within the immediate influence of calcareous rocks," whilst " high mortality is associated with flooded, low-lying, and clayey areas."

Now it is obvious that one registration district or county may cover an area over which the geological conditions are by no means uniform ; thus, for example, the Wealden area is here divided between the counties of Kent and Sussex, while the chalk extends over portions of many counties ; this fact was fully recognised by Dr. Buchanan in his observations on phthisis even in the comparatively simple area represented in the map on p. 26.

Even supposing that registration districts were very small indeed and corresponded absolutely with uniform geological districts—as we have endeavoured to show throughout this book—unless the *conditions* (sanitary and otherwise) are the same, we are not justified in concluding that the variations in death-rate are due to differences in geological characters.

We trust also that we have made it clear in the preceding pages that such a phrase as " the immediate influence of calcareous rocks " requires greater precision before much meaning can be attached to it.

Mr. Haviland then after forming the above conclusions with regard to cancer maps *explains* the facts by adopting the theory that cancerous diseases are due to some micro-parasite, and that since certain pathogenic organisms are inhabitants of the soil, there is a probability that the organisms concerned in cancer also exist in the soil ; and further that since the phanerogams (!) are selective, some thriving on calcareous soils alone and others only on clayey soils, we may expect the cryptogamic (!) microphytes

also to be selective, and in this way may be explained the relation between the nature of the soil and the prevalence of cancerous diseases.

Although there may be a possibility of some relation existing between micro-parasites and cancerous diseases, there is at present no proof that such is the case. (We are aware that some observers have recently described the occurrence of *protozoa* in cancerous cells.)   Mr. Haviland, however, not only adopts the bacterial hypothesis but goes still further and tells us from his cancer maps where these organisms exist and the kind of soil they most love, giving to " airy nothing a local habitation and a name." Surely it would at least be as well to wait until bacteriologists have captured the microphyte and proved its relation to the disease.

With regard to the heart-disease and phthisis maps, they are interpreted as showing the influence of climate rather than of soil.   We should like, however, to point out that no distinction at all is drawn between the different forms of heart disease.   It is perfectly true that endocarditis, especially mitral disease, is in the majority of cases caused by rheumatic fever, yet many other conditions bring about heart disease, such for instance as chronic endarteritis, arising from gout, alcoholism, syphilis, &c. &c. Maps showing the geographical distribution of mitral disease alone might be of some interest, provided migration never took place, as showing a relation between rheumatic districts and mitral disease ; heart-disease maps in which no distinction

is drawn between the various causes which produce the disease are, for the reasons given above, absolutely worthless.

We have said enough to show the futility of drawing practical conclusions from *registration returns* alone if we take account of only one condition in a complex series, useful though they may be in suggesting possible factors which would otherwise be overlooked.

Disease maps based on statistics obtained in a different manner were drawn up by the International Committee appointed by the Medical Congress of 1884 to inquire into the geographical distribution of rickets, acute and sub-acute rheumatism, chorea, cancer and urinary calculus. Questions were addressed to every registered practitioner in the United Kingdom ; not many more than 3,000 answers were received out of a possible 20,000, so that much weight cannot be attached to these statistics ; so far as they go, however, the results are distinctly opposed to Mr. Haviland's conclusions as regards cancer, except in London where the conditions (migration, hospitals, &c.), introduce great complexity.

Dr. Isambard Owen thus summarises the results of the enquiry :—" The red and purple " (colours which indicate a relatively small percentage of cases) " do not affect the sea coast, the mountainous districts, or the plains ; they do not follow the course of great rivers, or the spread of any particular geological formation ; they occur indifferently in poor and rich, in agricultural and industrial districts ; they appear alike in the north, the south, the east and the west."

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All such disease maps may, of course, be of great value in indicating the *geographical* distribution of disease, but let us beware of interpreting them as maps of the *geological* distribution (as Mr. Haviland has done in the case of cancer) until our statistics are grouped by similar geological areas where the other conditions are absolutely uniform.

INDEX

THE END

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